Open Reduction of Common Fractures

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Open Reduction of Common Fractures

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Contents

Preface

WHY SHOULD THERE BE A BOOK on open reduction of common fractures? The title requires some justification and elucidation. It is not meant to imply that open reduction should be a *common* method for treating fractures. Most fractures are best treated by closed methods. Open reduction, however, should be the prevalent method for treating many fractures, as will be outlined in this text. By a *common* fracture we do not intend to imply hackneyed, of inferior quality, trite or mediocre, because many fractures requiring open reduction are complex and are most difficult to treat by any method. We have attempted to describe those fractures that occur most frequently and which may be treated best by open reduction. This was the reason for the selection of the word *common*. When relatively uncommon fractures have been discussed, they are fractures in which open reduction has special merit.

Open reduction seems to bear an undeservedly poor reputation in some circles probably because the method is not evaluated objectively. The results of research now permit surgeons to perform many operations only imagined a few years ago. Every day surgeons open and patch the heart chambers as readily as they removed the appendix many years ago. We believe the treatment of fractures has failed to receive the same enthusiastic attack as the treatment of many other lesions. Various factors may be contributory. Fractures, although a challenging enough problem, are often considered a mundane subject when compared with, for example, lesions of the cardiovascular system. As ancient as the medical profession itself, routine fracture problems are neither new nor excitingly dangerous, and the delicate balancing of the factors which will produce perfect function may have failed to attract the most creative medical minds.

Certain poor results with open reduction have supplied an appealing text for countless contributors to the medical literature. No sadder picture exists than the roentgenogram showing a profusion of "hardware" that has been followed by nonunion and

osteomyelitis. A limb may be completely useless because the joints have become stiff, the muscles shriveled and the bone sharply angulated beneath a plaster cast. But the roentgenograms are so much more repulsive if they show broken "hardware." Isn't it true that the plaster cast, on the one hand, and the operative exposure of bone, on the other, are neither good nor bad, but derive their merit from how and when they are used and by whom? In inveighing against open reduction, many writers describe operations either performed improperly or for improper indications, for example, the use of a two hole plate covering a fracture of a long bone or a femoral shaft fracture in a child fixed by a plate and screws.

It has become almost axiomatic that fractures must be treated by the *conservative* method, evidently in contrast to other lesions, since the word conservative is never emphasized to the same extent in the treatment of other lesions. By the conservative method most writers on fractures seem to mean the *nonoperative* method. For treating fractures the medical student soon learns this magic word conservative. Not for treating cancer, not for treating congenital heart lesions, not for treating hypertension is this word conservative so accentuated to the student. It is reserved for fractures; fractures are beyond the pale. Why?

What does conservative treatment mean? The verb conserve comes from the Latin, *conservare*, meaning *to preserve*. It is defined in the *Oxford English Dictionary* as: "1. To keep in safety, or from harm, decay or loss; to preserve with care; now usually to preserve in its existing state from destruction or change. 2. To preserve or maintain in being or continuous existence; to keep alive or flourishing." In 1538 Starkey wrote, "kept and conservyed contynually in helth." The adjective conservative is defined as: "characterized by a tendency to keep intact or unchanged; preservative." The *conservative* treatment, then, is the treatment which *preserves* the person or thing which is being treated. Evidently, modern writers on fracture treatment employ conservative to describe the age of the treatment method itself, rather than to apply it to the patient being treated. This type of usage is described in Fowler's *Modern English Usage*: "Perhaps the most ridiculous of *slipshod extensions* is the rapidly spreading use of this word (conservative) as an epithet in the sense of moderate, safe or low with estimates, figures, etc."

Although the substitution of conservative for moderate is now

standard in American usage (Bergen and Cornelia Evans, *A Dictionary of Contemporary English Usage*), this use of conservative leads to ambiguity when describing the treatment of a patient. If we use conservative to describe treatment, should it not refer to the patient—not to describe his political party but to describe that treatment most likely to preserve his life and function? We try to use the conservative treatment for every fracture, just as for every other disease.

The late Clay Ray Murray dreamed the ideal treatment for fractures: to wish the fragments into place, to hold them there by moral suasion and to keep the patient on the job while the fracture heals. Until we build this utopia for fractures we must try to approach Murray's ideal by employing the conservative method for each specific fracture. To ascertain the conservative method for each specific fracture is often difficult. Whatever it may be, it is not necessarily the oldest method, nor open reduction, nor a plaster cast. To pinpoint the conservative treatment is simple at extremes of the spectrum. The conservative treatment for children is rarely open reduction. The 80 year old lady with an impacted fracture of the neck of the humerus needs no treatment, or the treatment of skillful neglect. If the same lady fractures the neck of her femur, she needs prompt operation and internal fixation of the fracture, or replacement of the femoral head by a prosthesis. For both fractures, we have selected the conservative method. For the latter fracture, open operation is conservative, because operation and internal fixation is the treatment most likely to preserve the life and function of the patient. Between these two extremes lie many difficult fracture problems.

To select the truly conservative treatment, many factors have to be weighed. The conservative treatment is not static. It may change from week to week and hospital to hospital. Some factors to be considered follow.

The Relative Importance of Function to the Patient: A shattered elbow may justify operation and internal fixation in a young laborer but not in our 80 year old lady. Surgeons may underestimate the primacy of time and function to the patient in their concern with preventing death or life-endangering complications. The laborer with a fracture of his elbow who must use his hands to make a living is willing to accept the risk of open reduction if it will significantly decrease time of treatment and minimize disability.

The Skill of the Surgeon: The conservative treatment for a specific fracture may be open operation in the hands of a skilled and experienced bone and joint surgeon but balanced skeletal traction suspension for others.

Operating Room Facilities: The surgeon who does not have a completely equipped operating room at his disposal must have imperative reasons for operating on a fracture. Few patients with fractures demand such urgent treatment that they cannot be transported to hospitals with the necessary equipment.

Anesthesia: Patients with fractures are often difficult anesthetic problems. Many are admitted to the hospital with full stomachs. If the child with a supracondylar fracture of the elbow dies from aspirated vomitus, the surgeon's life is haunted and should be. The surgeon treating fractures is indeed fortunate if he has a skilled anesthetist as a colleague. In determining the conservative treatment for a specific fracture, the physician must weigh the quality of available anesthesia.

Nursing Personnel: Russell traction produces excellent results in some hospitals for the treatment of trochanteric fractures of the hip. To be effective, however, Russell traction needs an intelligent, specially trained and enthusiastic nursing staff on the fracture service. Such a nursing staff may make Russell traction the conservative method for treating a specific trochanteric fracture.

Incidence of Pathogenic Bacteria: If infection with *Staphylococcus aureus* is rampant in a hospital, open operation may not be *conservative* for any fracture.

We hope then that before the methods of open reduction described in this monograph are used, these and all other factors will be considered carefully and if, after careful study, open reduction is believed to be the truly conservative method, that it will be used.

We make no claim of originality for any of the operations described. We have drawn freely from the literature, but have selected the operations which we ourselves have found most useful. We hope that we may have performed a service by bringing together in a relatively concise monograph technics which, if employed properly and for proper indications, will aid the patients with fractures.



1 *General Considerations*

THE OBJECTIVES OF MANAGEMENT OF FRACTURES

THE IDEAL MANAGEMENT of a fracture accomplishes a solidly united fracture in perfect alignment, a bone of full length and joints freely movable by normal musculature, all within the shortest possible time; stated in another way, the rehabilitation of the whole patient as quickly as possible.

William Darrach, in his presidential address before the American Surgical Association in 1946, summarized the objectives of fracture management under the following headings:

1. Reduction of secondary trauma to a minimum.
2. Sufficient restoration of normal form to meet the requirements—this may be short of the ideal anatomic reduction.
3. Immobilization of the bone fragments until healing has occurred—all joints should be mobilized immediately if their movement does not cause motion of the fragments.
4. Restoration of function as early and as rapidly as possible and the atrophy of disuse minimized by the early institution of active motion.
5. Sustaining of morale and physical and social rehabilitation.

Unfortunately, it is impossible to obtain a complete functional restoration in many fractures. In some, shortening must be accepted to obtain enough contact of fragments to predispose to union. In others, particularly in fractures about the joints, the injury itself results in restrictive fibrous tissue proliferation which, combined with the necessary immobilization to permit union of the fracture in good position, is likely to leave some loss of motion in the joint adjacent to the fracture. Atrophy of the musculature is a natural consequence of prolonged immobilization and the patient, despite strenuous efforts later, may not be able to rebuild his muscle strength entirely. Yet, most fractures require considerable immobilization in order that union may be obtained.

Even though some limitation of function is inevitable because of the injury itself or the indicated treatment, the surgeon must

make every effort to minimize the eventual limitation of function. Throughout the course of treatment he should direct continuing efforts toward functional restoration of the part and the patient as a whole. In certain fractures, for example fractures about the surgical neck of the humerus, some malposition and resulting deformity of the bone should be accepted in order to minimize immobilization and permit early active exercises which experience has shown will lead to the best return of function of the extremity.

The objectives of management of a fracture depend somewhat on the location of the fracture. In the lower extremity, stability without pain is the most important objective. Pain-free movable joints for locomotion with good strong musculature and full length of the extremity are also important but, in many fractures, these must be compromised to some extent to insure a solidly united fracture which will provide painless stability on weight-bearing. In the upper extremity, on the other hand, the most important objective is the maintenance or return of full function of the hand. This should not be jeopardized by overzealous treatment of the fracture, although stability is needed for the maximum function of the hand. Perfect alignment is desirable, yet union in slight angulation may be of no consequence and certainly the fracture may heal with some shortening without any real loss of function of any of the parts of the extremity.

METHODS OF MANAGEMENT OF FRACTURES

All methods of management of fractures may be classified under five general headings:

1. Closed reduction (or maintenance of reduction in undisplaced fractures) and immobilization, usually with a plaster cast.
2. Continuous balanced traction, usually skeletal traction.
3. *Open reduction, usually with internal fixation—the operative method.*
4. External skeletal fixation (including transfixion pins incorporated in plaster).
5. No immobilization (perhaps a sling or a bandage).

Each method of management has its advantages and disadvantages to be weighed carefully by the surgeon in selecting the best for each fracture. The choice of a method is based on several factors. Of these, the contour of the fracture and its location in the

broken bone, as revealed by the roentgenograms, are probably the most important. Others to be carefully evaluated include whether the fracture is open or closed, the presence of other significant injuries, the age and general condition of the patient and, if open reduction is under consideration, the status of the circulation to the soft parts, particularly the overlying skin through which the incision is to be made. The equipment at hand and the experience and ability of the surgeon are also important considerations.

ADVANTAGES AND DISADVANTAGES OF OPEN REDUCTION

Open reduction and internal fixation in the hands of a skilled operator affords the most exact reduction of fragments of any method of management of fractures and offers many advantages. This excellent reduction predisposes to rapid union. A stable internal fixation insures against loss of reduction later and contributes to the immobilization of the fragments. It may eliminate the need for external fixation (as with intramedullary nailing in fractures of the femoral shaft) or allow early removal of a cast to permit the return of function of adjacent joints and the entire extremity.

Open reduction and internal fixation also carries several disadvantages. A closed and, therefore, uncontaminated fracture is converted into an open fracture with the risk of infection. The operation itself adds to the damage to soft parts and bone. The operative scar, superficial and deep, always remains. Periosteal stripping incident to the exposure of the cortex of bone for application of internal fixation actually devitalizes at least the outer third of the cortex. This is usually of little significance as reattachment of soft parts leads rapidly to revascularization but if postoperative sepsis should follow, soft parts may not reattach to the cortex and massive sequestration may occur. With open operation, the original hematoma about the fragment ends is lost and, therefore, any value this has in promoting union of the fragments is eliminated.

Moreover, certain forms of internal fixation, such as a standard plate held rigidly to the fragments by screws, can serve to delay union of the fragments. In practically every fracture, some absorption of the ends of the fragments occurs. The normal tone of the surrounding musculature cannot approximate the fragment ends to compensate for this absorption if they are strutted apart by a plate and screws and, therefore, a narrow but definite gap may persist

between the fragments and predispose to nonunion. An effort to circumvent this disadvantage of plates and screws has led to the development of slotted bone plates (Eggers principle), which theoretically allow for some sliding of the screw heads along the slots of the plate as fragments are drawn into firm, constant contact by muscle tone. Although they appear advantageous and certainly they permit firm impaction of the fragments at the time of operation, there is some doubt whether the screws can slide in the slots for more than a few days following operation. Excessive absorption between fragments may lead to a persisting gap even with a slotted plate.

Other forms of internal fixation, particularly if used improperly, also may deter or prevent union of the fracture rather than facilitate it. An intramedullary nail which binds too tightly in the canal of a distal fragment may lead to the fragment being driven and held apart so as to create a gap in the fracture site. An intramedullary nail which is not tight enough may allow continuing rotation in the fracture site and predispose to nonunion.

In summary, open reduction and internal fixation of fractures is a calculated risk affording many advantages but carrying some definite disadvantages. The majority of the latter can usually be circumvented by proper selection of cases for this method of management and by avoiding technical pitfalls. Open reduction and internal fixation may be selected as the method of management for a given fracture when the advantages outweigh the disadvantages.

INDICATIONS FOR OPEN REDUCTION

Open reduction of fractures may be classified as:

1. Primary: Performed as the first definitive method of management without previous attempts to use any other method.

2. Secondary: Performed after one or more of the other methods have been unsuccessfully applied.

Because the selection of open reduction and internal fixation for a specific fracture depends on many variables and its advantages and disadvantages as evaluated by the surgeon, a rigid classification of indications for primary open reduction cannot be formulated. Obviously, the indication for secondary open reduction is usually the failure to achieve satisfactory apposition and alignment of the fragments by other methods. Occasionally, a secondary procedure

will be selected for functional advantages even though the reduction by another method is good.

Indications for primary open reduction may be classified as follows:

1. Fractures requiring open reduction because satisfactory apposition and alignment of the fragments cannot otherwise be obtained and maintained.

Many displaced fractures cannot be brought into good apposition and alignment and held there by closed methods often enough to justify the use of any method other than open reduction and internal fixation. Examples are displaced and overriding fractures of the shafts of both bones of the forearm in adults, separated fractures of the patella, trimalleolar fracture-dislocations of the ankle which include a posterior malleolar fragment of more than one-third of the articular surface, displaced fractures of the neck of the femur and rotated fractures of the lateral condyle of the humerus in children.

2. Fractures requiring open reduction if the best functional restoration of the extremity is to be achieved, even though closed methods might give good reduction of the fragments.

In many fractures adequate reduction may be achieved with other methods and, in the end, roentgenograms would show a good result. The functional result, however, would be inferior to that anticipated with open reduction. The latter method, therefore, is usually the preferred method of management for such fractures. Examples are fractures of the shaft of the femur in adults, separated fractures of the olecranon and many supracondylar fractures of the femur.

3. Fractures requiring open reduction if life-endangering periods of recumbency and restriction of activities are to be avoided, even though closed methods might give good apposition and alignment of the fragments and a high percentage of union of the fractures.

The classic example of this group is a trochanteric fracture of the femur. Traction methods usually give excellent reduction of the fragments, which usually unite readily. Open reduction and internal fixation of these fractures, however, not only result in a lower hospital mortality than other methods, but the incidence of painful and disabling complications is decreased. These same advantages accrue in the operative management of fractures of the neck of the femur.

4. Fractures associated with injuries to major blood vessels or nerve trunks.

When the major artery of an extremity has been damaged, open reduction and internal fixation of an associated fracture may be imperative to facilitate repair or grafting of the injured artery. Moreover, internal fixation of a fracture may prevent occlusion of an intact vessel over the edge of a displaced bone fragment.

The presence of major peripheral nerve injuries in association with fractures may balance the scales in favor of open reduction and internal fixation of the fragments, even though other methods of management might give good apposition and alignment. Open reduction of the fracture permits exposure of the injured nerve trunk, its release from the fracture site and an accurate appraisal of the injury to the nerve. If the nerve trunk is lacerated, delayed repair at another operation is usually preferable to primary repair in the presence of a fracture.

5. Open fractures which cannot be reduced and kept stable by other methods.

In open fractures internal fixation is a calculated risk but this risk may be less than that of a displaced fragment extruding into or through the open wound or impinging against already devitalized muscle or skin, which may lead to necrosis.

A classic example of this indication is a trimalleolar fracture dislocation of the ankle with an open wound on the medial side through which the lower end of the shaft of the tibia is protruding. Internal fixation of the medial malleolus will frequently serve to stabilize all of the fractures in good position and thereby avoid the tendency toward lateral redisplacement which, in turn, could cause pressure of the distal end of the tibia on the skin of the medial side of the ankle from within and lead to pressure necrosis. When it is indicated, open reduction should usually be carried out at the time of débridement of open fractures.

CONTRAINDICATIONS FOR OPEN REDUCTION

The general condition of the patient must be adequate to withstand anesthesia and the trauma of the operative procedure because life itself must not be endangered excessively even if the result of treatment of the fracture is less than desirable. Other factors, although they cannot be considered absolute, are at least strong deter-

rents against open reduction and internal fixation. Unhealthy skin at the site of a possible incision mitigates against open reduction. This may be an open skin lesion, furuncle or merely skin with such poor vascularity that wound-healing would be jeopardized. With these, the danger of sepsis and chronic osteomyelitis is usually too great to permit open reduction. Open reduction is contraindicated for almost all fractures in children, especially those of the long bones (p. 25). An additional important contraindication is the lack of adequate equipment for the operative procedure itself, and of first importance, the lack of qualifications and experience of the surgeon in this method.

TIMING OF OPEN REDUCTION

The optimum time for open reduction is promptly after injury, before excessive swelling has developed. With the fragments stabilized in excellent position by early operation and with good immobilization and elevation of the extremity, the swelling will actually be minimized. Once excessive swelling has occurred, the operative attack on the fracture often must be postponed rather than accept the risk of ischemia of the sutured skin margins and resulting slough and perhaps catastrophic infection.

The general condition of the patient, however, may make it desirable to delay operation. Uncontrolled diabetes should first be brought into control; cardiac decompensation should be overcome by appropriate measures; patients with decreased blood volume may require transfusions; other life-endangering injuries may require extensive management before definitive reduction of the fracture. Delay of open reduction, however, should not be too prolonged under these and other circumstances. If study and treatment of the patient is vigorous, the optimum condition for operation can usually be achieved within at least 24 hours after injury. A longer period of delay is likely to be for the convenience of the surgeon or internist rather than for the best interest of the patient. The proper treatment of fractures of a long bone may be delayed too long in an unconscious patient. The surgeon may be chagrined when the patient completely recovers from the head injury but is left with an unnecessarily crippled extremity. Obviously, the most precise judgment of co-operating specialists is required in these and similar combined injuries.

The presence of food in the stomach may dictate at least some delay in operation even though during that time excessive swelling may occur and further delay may be necessary. Except in a real emergency, at least 8 hours should be allowed to elapse after the last meal before the patient is given a general anesthetic. To anesthetize a patient with food in the stomach risks vomiting, aspiration and pneumonia and its dire consequences.

TECHNICAL PRINCIPLES OF OPEN REDUCTION AND INTERNAL FIXATION

Equipment and Materials

First-class operative management of fractures requires both first class instruments and reliable internal fixation material. The many special instruments now available through surgical supply houses are not, in a great majority, "fetishes" as they have been called by some, but, on the contrary, are important and, at times, invaluable aids in achieving effective and expeditious application of internal fixation devices without excessive damage to soft tissues and bones. The surgeon undertaking the operative management of a fracture should have available any and all of the instruments which might, under adverse developments, be necessary for a technically satisfactory operation. Tools to the bone and joint surgeon are as valuable as brushes and paints are to the artist.

All materials for fixation of fragments of bone have as a basic requirement "inertness in the tissues." Fortunately, basic and clinical research, combined with improved metallurgy have produced alloys which, for all practical purposes cause so little, if any, reaction in the tissues that the surgeon need have no hesitancy in implanting large quantities or masses of similar metals in the bone under good physiologic and surgical principles. Materials of quality are available to the surgical artist if he has the talent to use them.

For all practical purposes in this day, all internal fixation devices are fashioned from no. 317 SMO stainless steel, a chromium-nickel-molybdenum-iron alloy, or from Vitallium, a chromium-molybdenum-cobalt alloy. When properly annealed and passivated, each is most inert in the tissues. Each has certain advantages and disadvantages.

Stainless steel may be forged, cold worked or machined. Implants for internal fixation of fractures, therefore, can be fashioned of precise and intricate design. The screws carry sharp threads and uniform head slots for the appropriate screwdriver. Stainless steel, how-

ever, may not have been properly annealed, may have age-hardened, or have been work-hardened by excessive bending and is, therefore, not of uniform hardness; as a result, a particular internal fixation device may not have sufficient stability and strength, and postoperative bending may occur. SMO stainless steel for internal fixation of fractures usually should be of a uniform Rockwell hardness of C35, since such a degree of hardness provides adequate stability and still gives enough ductility to permit proper designing. In addition, different items of SMO stainless steel of different composition and properties should not be used together as this may dispose to some electrolytic corrosion in the tissues. Where stainless steel devices, hip nail plates for example, are fashioned from SMO stainless steel of Rockwell hardness C35, adequate stability and strength are usually provided, and if the screws used with this nail are of a material of the same composition and properties, the fear of significant electrolytic reaction in the tissues may be discounted.

Vitallium, on the other hand, must be microcast. It cannot be forged and can be cold-worked and machined only with great difficulty. Designs may not be so uniform and their precision and intricacy are limited to the microcast method. Certainly, the threads of screws are not as sharp as those made from stainless steel. Moreover, at times the slots in the screws for the screwdriver are not of uniform size. For these reasons, Vitallium screws often are more difficult to insert than those of stainless steel; but, if properly inserted, their holding power is as good as those of stainless steel.

On the other hand, Vitallium of the same mass is stronger than stainless steel. For example, a nail-plate of Vitallium for an intertrochanteric fracture of the femur has been shown to be stronger at the angle than one of the same design and mass of SMO stainless steel. When strength is needed, particularly at an angle, Vitallium is probably preferable. For example, when a hip nail-plate with a long plate is used for a subtrochanteric fracture in a muscular individual, a Vitallium nail-plate is most advantageous. It must be attached with Vitallium screws. Stainless steel and Vitallium should not be mixed in the internal fixation of a fracture.

Principles of Surgical Exposure of Bones

Incisions in the skin in general should be made in the location giving the easiest access to the site of the fracture without significant danger of injury to major blood vessels and nerve trunks. At times,

however, an incision should be placed in a location of poorer access to bone in order to avoid scarring of certain muscle groups which could lead to impairment of function. For example, in an intramedullary nailing of a fracture of the shaft of the femur, the posterior-lateral approach is preferable. The approach to the bone is somewhat more difficult through this incision than through an anterior-lateral approach, but the former places the scar posteriorly and does not disturb the quadriceps musculature and, therefore, the important quadriceps function is not impaired. In general, an incision should not be made along the crest of a long bone—for example, not along the crest of the tibia or ulna—but rather a short distance to one side so that when the wound has healed the scar will not overlie a bony prominence, such as a crest. The incision should be sufficiently long to permit adequate exposure of the fragments without excessive retraction of the soft parts which may cause necrosis.

The fracture site should be approached through intermuscular planes when possible. At times, this is not possible and muscle bellies must be incised. An example is the necessity of incising the brachialis muscle for exposure of the middle third of the shaft of the humerus. In such instances, it is better to incise the muscle by sharp dissection rather than tear it with blunt dissection. Throughout the operative procedure, trauma to muscle bellies and skin must be held to the minimum. It is possible to minimize trauma to the soft parts without handicapping the internal fixation of the fracture.

Periosteal stripping is necessary for exposure of bone cortex but this also must be held to the minimum. The outer third of the external cortex of bone receives its blood supply through the periosteum and when the periosteum is stripped, this portion of the cortex is devitalized. Fortunately, revascularization usually takes place rapidly. Regardless, useless and unnecessary stripping of periosteum should be avoided. Particularly, periosteal and other soft tissue attachments to comminuted fragments should be safeguarded.

Methods of Internal Fixation

Internal fixation of fractures may be provided in a number of ways (FIG. 1). These include one or more screws; plates held by screws, threaded or unthreaded pins cut off as nails; blade-plates, nails, pins and bolts of special design; intramedullary nails or pins; and loops

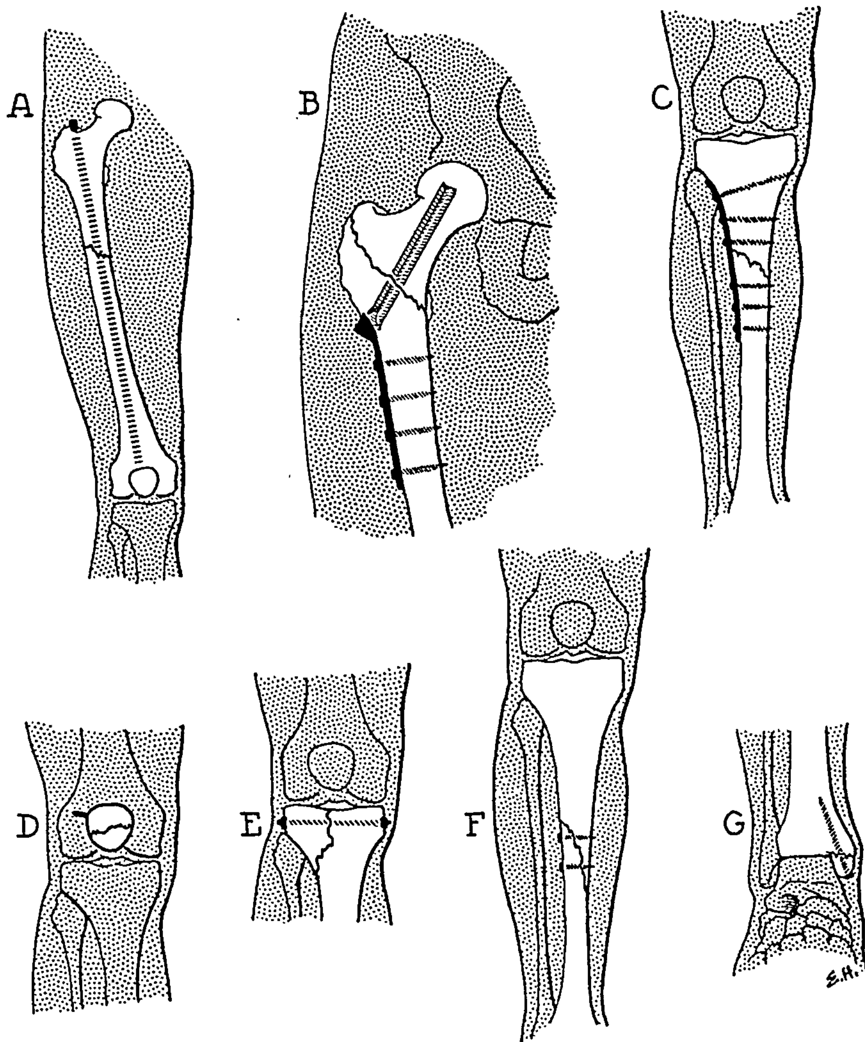


FIG. 1—*Methods of Internal Fixation.* (A) Intramedullary nail for fracture of the femoral shaft. (B) Jewett-type nail plate and screws for trochanteric fracture. (C) Moulded plate and screws for fracture of proximal portion of tibia. (D) Circumferential wiring with malleable wire for fracture of patella. (E) Webb bolt for fracture of lateral condyle of tibia. (F) Multiple screws for oblique fracture of shaft of the tibia. (G) Screw for fracture of medial malleolus.

of stainless steel malleable wire (FIG. 2). When required, any combination of these methods may be employed in any given fracture.

Plates and Screws: The use of plates and screws for internal fixation is applicable only to fractures of the shaft of long bones except under unique circumstances. The fracture of the shaft may be transverse, mildly oblique (near transverse), oblique or spiral or mildly comminuted. Extensive comminution usually contraindicates this method.

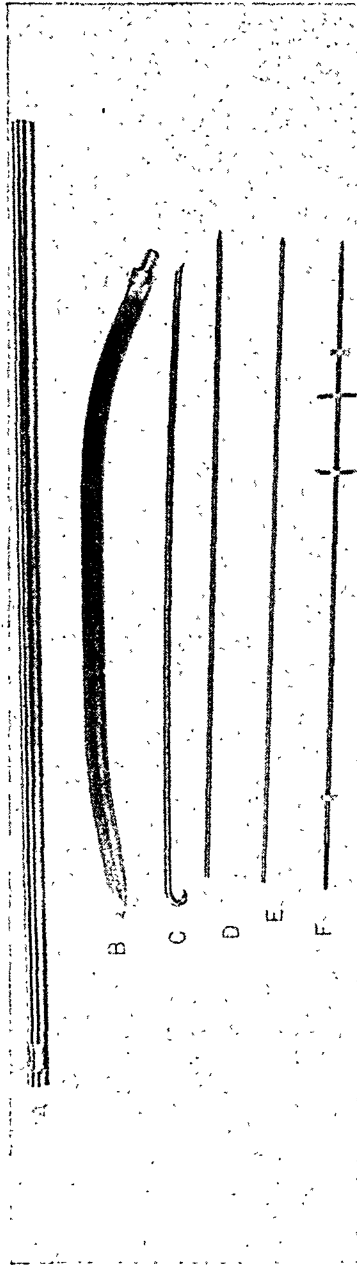


Fig. 2—*Materials for Internal Fixation of Fractures*. Those shown within the enclosure (fig. 2 G–J; *top, left*, page 13) are of vitallium; the remainder are of SMO stainless steel. (A) Clover-leaf (Kuntscher) intramedullary nail for fractures of the femoral shaft. (B) Lottes intramedullary nail for fractures of the tibial shaft. (C) Rush pin of intermediate size for fracture of bones of the forearm. (D) Threaded pin. (E) Unthreaded pin. (F) Webb tibial belt.

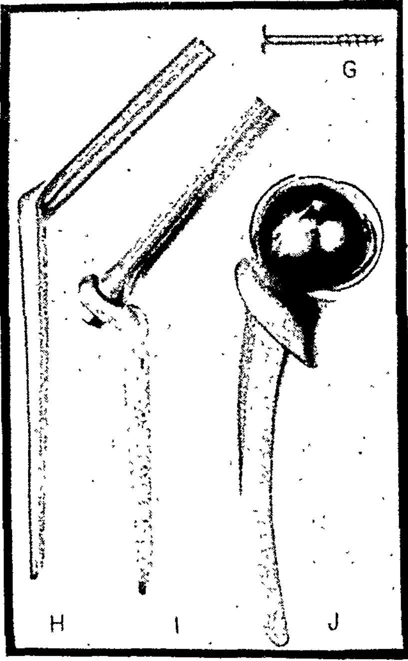


Fig. 2—(G) Bosworth screw (for internal fixation of the clavicle to the coracoid in an acromioclavicular separation). (H) Jewett hip nail of vitallium. (I) McLaughlin two-piece hip nail. (J) Fred Thompson hip-joint endoprosthesis. (Note that the highly polished head actually reflects the image of the photographer.)

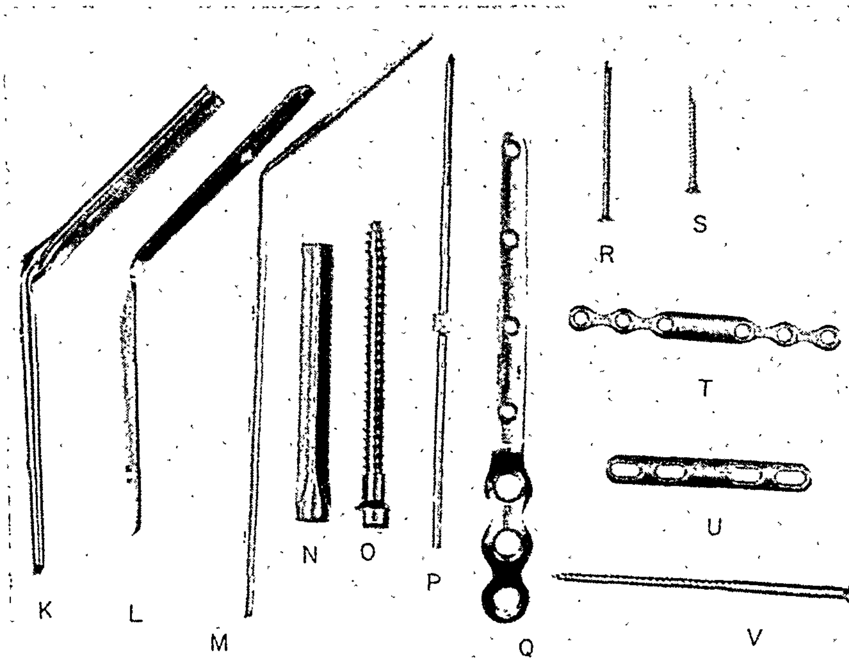


Fig. 2—(K) Jewett stainless steel hip nail. (L) Neufeld hip nail. (M) Moore hip nail (which can be moulded and used for supracondylar or T-fractures of the femur also). (N) Smith-Petersen hip nail. (O) Lorenzo screw for fractures of the neck of the femur. (P) Knowles pin. (Q) Moe plate. (R) Bone screw with machine threads and pilot point. (S) Bone screw with wood threads. (T) Standard bone plate. (U) Slotted bone plate. (V) Wood-type screw.

Prior to the advent of intramedullary nailing which, in the majority of instances, is applicable to the same types of fractures, internal fixation by means of plates and screws was probably the most frequently employed. In recent years, the method has been used less and less, principally because in general, intramedullary nailing has been shown to be more effective in obtaining the desired end-result. Moreover, plating has been shown to have distinct potential disadvantages and hazards, chiefly that of strutting the ends of the fragments apart (p. 3; FIG. 3A). Plates and screws, however, do offer



FIG. 3—*Standard and Slotted Plates.* (A) Improperly plated tibia using a standard plate. The gap at the fracture site of the tibia will persist and enlarge and nonunion is almost certain to follow.

an acceptable means of internal fixation for some fractures of the shafts of long bones, particularly those too near the ends of the bones for intramedullary nailing.

The plate may be standard (unslotted) or slotted (Eggers; FIGS. 1–3). Either should be a six hole or four hole plate. Rare indeed is there a need for a two hole plate. Theoretically, the slotted plate is preferable as it allows for continuing contact of the fragments by the impacting effect of normal muscle tone. Practically, actual sliding of the fragments together may not take place during the healing phase of the fracture but certainly the slotted plate does permit the fragments to be firmly impacted manually before the screws are tightened at the time of the operative fixation.

In applying a slotted plate, the drill holes should be prepared and screws inserted at the end of the slots most distant from the frac-



FIG. 3—(B) Properly plated tibia using a standard plate with an additional oblique screw through the fracture site. The fragments are plated in firm contact which predisposes to union.

ture site. Each screw should be inserted to a point where the ongoing tip is barely engaged in the cortex opposite the plate. Then an assistant manually impacts the fragments. Then each screw is advanced farther. A fundamental principle used by Eggers is actually not to tighten any of the screws in order to allow for subsequent sliding along the slots as the fragments are drawn together by the tone of the muscles. The use of this principle, however, becomes a matter of preference for the surgeon in each operation.

Plates should not be placed on the subcutaneous surface of a bone but rather on a surface which will subsequently be covered by muscle as well as skin. For example, the proper location for a plate on the tibia is the anterolateral surface. Usually, a plate should be four to five times as long as the diameter of the bone at the fracture site. It should fit flush against the cortex of the bone. When a plate is



FIG. 3—(C) Plated tibia using the Eggers slotted plate.

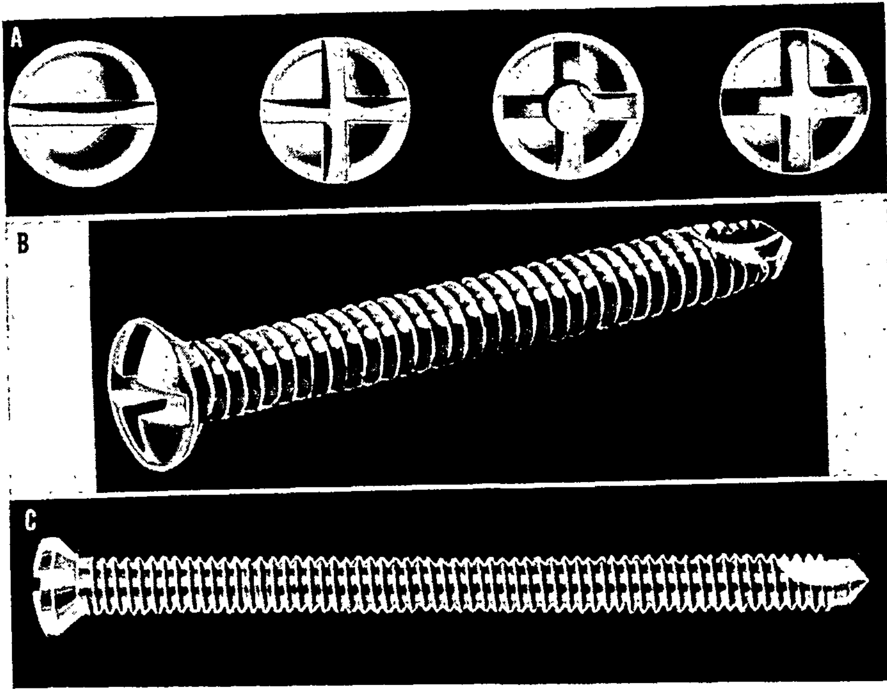


FIG. 4—*Screw Designs.* (A) Four types of screw heads, each requiring a different type of screw driver, single slot, cross-slot, simulated Phillips and concave cross-slot. (B) A screw with a concave cross slot head and machine threads (and also pilot point poorly shown). (C) The same type screw showing the pilot point. (Courtesy of The Orthopedic Equipment Company, Bourbon, Indiana.)

used near the end of a long bone, some preliminary bending or molding is often necessary to make it lie flush along the cortex of each fragment.

Screws may carry close machine threads or coarse wood threads. Neither has any advantage over the other. Tests have demonstrated that each has about equal holding power.

The screw heads may carry standard slots or the newer concave cruciate slots (FIG. 4A). The latter require the special convex cruciate screwdriver. The cruciate screw head appears to be advantageous. It facilitates insertion and does not require a screw-holding screwdriver, an instrument which tends to cause the screw to fail to follow the drill path precisely.

The standard screws have a shaft 7/64 inch in diameter and a total diameter of 9/64 inch, including the threads. An important relatively recent modification in screw design is the small pilot point on the distal end of the screw (FIG. 4C). This point is of the same diameter as that of the shaft of the screw without the threads. It

actually seems to seek the drill hole in the distal cortex as the screw is inserted and is definitely advantageous.

Drill holes for the standard caliber screws should be made with sharp drill bits of 7/64 inch diameter, except in special instances. Drill bits with flutes extending only one-half inch or so from the tip appear preferable. The fact that the remainder of the drill is smooth avoids scoring and enlarging of the hole in the proximal cortex as the drill bit is advanced through the opposite cortex and, therefore, the holding power of the screw in the proximal cortex should be the maximum. A special screw-centering instrument for the drill provides an added refinement in technic (FIG. 5). It insures that the drill hole is made in the center of the hole in the plate. This, in turn, insures that the screw will not impinge on the margin of the hole in the plate as it is inserted and that the head of the screw will seat smoothly without binding (FIG. 6).

Screws for fixation of a plate to the shaft of the bone should be inserted parallel with each other rather than in a staggered fashion. The holding power of a group of parallel screws exceeds that of an equal number of screws placed at different angles. Each screw should pass through both cortices. The small pilot point of the newer screws should project just beyond the cortex opposite the plate.

Single Screw or Multiple Screws: The use of single or multiple screws for internal fixation is applicable in certain fractures of bony prominences such as those of either the medial or posterior malleolus, in some oblique or spiral fractures of the shaft of long bones and at times in comminuted fractures to fix a fragment in place as a supplement to other methods of internal fixation.

In the fixation of a bony prominence by one or more screws, the hole for the screw must be prepared precisely, as described above for the use of screws with plates. Ideally, the screw should pass through the opposite cortex for increased stability although this is not always necessary. In some instances, such as in the internal fixation of a fracture of the medial malleolus, a screw of sufficient length takes adequate purchase for stability in the cancellous bone of the contiguous tibia. In such instances the drill hole need not be prepared to the depth which will be reached by the screw.

In the fixation of oblique or spiral fractures of the shaft of a long bone the following points in technic deserve mention. Except in rare

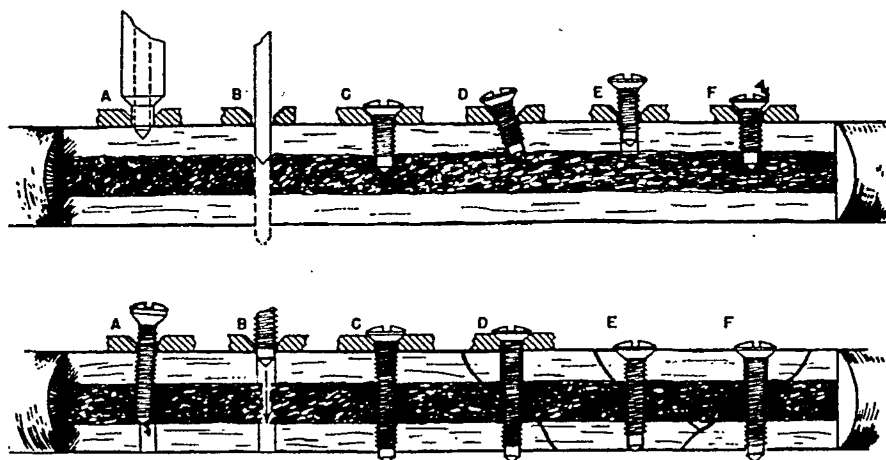


FIG. 5—*Principles for Fixation of a Plate to Bone with Screws. Above.* (From Peterson, L. T.: Fixation of bones by plates and screws. J. Bone & Joint Surg. *29:* 335 [April] 1947.) (A) The use of the drill guide ensures the proper centering of the screw in relation to the hole in the plate. (B) After the hole has been started, the guide is removed and the hole is drilled through one or both cortices. If the guide is kept in place, it will tend to become filled with bone chips. (C) A screw, properly centered and perpendicular to the plate. The head of the screw fits the countersink accurately. (D) A screw inserted at an angle. The threads are likely to be damaged by the edge of the plate. The head comes into contact with the plate at only one point instead of uniformly as in C. (E) A screw inserted perpendicularly, but eccentric to the hole in the plate. This is common if a drill guide is not employed. The threads are likely to be damaged if sufficiently eccentric, since the clearance between screw and plate is only from 0.009 to 0.020 inch. (F) As the screw in E is tightened, the head will be forced into the countersink in the plate. This lateral force on the screw tends to cause excess pressure and to strip the threads already cut in the bone.

FIG. 6—*Importance of Pilot Point in the Insertion of Screws. Below.* (From Peterson, L. T.: Fixation of bones by plates and screws. J. Bone & Joint Surg. *29:* 335 [April] 1947.) (A) A long screw without pilot point has been inserted at a slight angle in relation to the drill hole. This is common in actual practice. The point may completely miss the hole or it may hit it eccentrically. Then, as it is forced into line, it will tend to strip the threads already cut in the proximal cortex. (B) A screw with the pilot point. The tip accurately fits the drill hole and tends to direct the screw properly. Furthermore, it holds the screw, so that it may be more easily controlled without the use of a screw-holding device on the screw driver. A longer pilot point would be more effective for both purposes, but this portion of the screw does not engage the bone. (C) A long pilot point screw, properly centered and of optimum length. (D) After both cortices have been drilled with a no. 35 drill, the hole in the proximal cortex has been enlarged by a no. 27 drill (0.144 inch) so that the threads engage only the distal cortex. In this case the whole screw acts as a pilot point. This method makes possible the impaction of fragments when the screw is tightened. (E) Two fragments of bone, fixed with a screw without use of a plate. The hole in the proximal cortex has been countersunk. This avoids the tendency for the tapered head to split the bone and also makes the head less prominent. (F) The proximal hole has been both enlarged as in D and countersunk as in E and permits impaction of the fragments. Methods E and F are applicable in fixation of fragments and of onlay bone grafts.

instances, two or more screws should transfix the fracture. These screws should be placed at an angle of 90 degrees to the long axis of the bone and parallel to each other, not staggered. If the drill holes in the proximal cortex (the cortex through which the screws will pass first) are made as large or slightly larger than the overall diameter of the screws (9/64 inch), a snugging lag effect is produced as the screws are tightened. These principles of technic are applicable in the supplementary use of screws to stabilize a comminuted fragment.

Threaded or Unthreaded Pins (FIG. 2D AND E): These may be applicable for the same types of fractures as a screw or screws when the purchase and stabilizing effect of the screw head is not necessary. They are valuable when the fragment to be fixed is so fragile that it could be split by the insertion of a screw, for example, T-fractures of the distal humerus. The pin is inserted to the proper depth as if it were a drill bit and then it is cut off flush with the cortex of the fragment.

Blade-plates, Nails, Special Pins and Bolts of Special Design (FIG. 2): These, too, are used in fractures of the ends or bony prominences of long bones such as those of the neck and trochanteric region of the femur, condyles of the femur and condyles of the tibia. The principles for their insertion conform to those outlined above for the use of plates and screws.

Loops of Malleable Wire: Except for fractures of the patella and some fractures of the olecranon, this method is used alone only in exceptional instances. Wire loops may be employed supplementary to other methods to hold major fragments in contact or to hold a comminuted fragment in adequate reduction. It must be remembered that loops of wire seldom really stabilize fragments in reduction except in fractures of the patella and olecranon.

The wire should be large and strong. Usually 18, 20 or 22 French caliber wire should be employed. The loops may be placed circumferentially around fragments (as in some fractures of the patella) or through drill holes passing through both cortices of each fragment (as in some fractures of the olecranon). In the partial fixation of comminuted fragments, the loop of wire may pass through only one cortex of each as a kind of wire suture.

Intramedullary Nails (or Pins): These latest developed and highly significant devices for internal fixation of fractures are ap-

plicable to a great many fractures of the shafts of all of the long bones except the humerus, where their use is seldom preferable. They may be used effectively in many fractures too comminuted for fixation by either screws alone or a plate and screws.

An intramedullary nail must be regarded merely as an internal splint which is employed to hold or help hold the fragments in adequate reduction while they unite by the normal process of bony union. It is not to be regarded as something which has been used to "nail the fragments together" so securely that healing of the fractures is not needed.

The principle of intramedullary nailing does have many advantages. The method provides a means of internal fixation of double and triple fractures and fractures with moderate comminution, including those with a large butterfly-shaped fragment. These are fractures which are not ideal at all for other methods of internal fixation. Intramedullary nailing requires an open reduction (except in most tibial fractures, p. 163), but the operative trauma including periosteal stripping is less than with any of the other methods. Apparently of great significance, this method allows for continuing contact compression of the fragments as the result of normal muscle tone which continuously holds the distal fragment firmly against the proximal fragment. It seems reasonable to state that intramedullarly nailing has led to as high or a higher percentage of union as any other method of internal fixation of fractures of the shafts of long bones.

In the great majority of fractures of the femur, intramedullary nailing offers another important advantage. Except in some adverse situations (for example, some double fractures or some fractures at the junction of the middle and lower third for which intramedullary nailing has been selected), the intramedullary nail affords enough protection against the usual angulatory, side-to-side and rotary strains to permit all external splinting to be omitted. Such stability permits early mobilization of the patient on crutches, abundant exercises of the joints and musculature of the injured extremity and all-in-all better and earlier functional restoration of the extremity.

This tremendous advantage of intramedullary nailing for fractures of the shaft of the femur (that is, no need for external splinting), is seldom gained with intramedullary fixation of fractures of

the other long bones. External splinting, usually a plaster cast, is essential for these because intramedullary nails in the tibia, humerus and bones of the forearm do not alone provide enough immobilization of the fragments. With this method of internal fixation in these fractures, however, plaster casts can be discarded earlier than with other forms of internal fixation. In tibial fractures, a walking cast may be safely employed much earlier after fixation by an intramedullary nail than after fixation by a plate and screws or by multiple screws.

Several errors in technic which could favor nonunion of the fracture or otherwise negate the advantages of intramedullary nailing may easily be avoided. The intramedullary nail must be neither too short nor too long. The diameter of the nail must not be too large or the fragment in which the nail binds may be exploded into a severely comminuted fracture. Neither can it be too small or the stabilizing effect will be lost. A careful preoperative study of the roentgenograms, including those of the uninjured counterpart of the opposite extremity, is invaluable in avoiding these errors in technic. If the on-going nail meets undue resistance, as though it had engaged in cortex, it must be withdrawn and reinserted in a slightly different direction. If a nail is driven forcibly through a cortex, extraction may be difficult even with a complete set of well designed and strong instruments for extraction.

Designs of intramedullary nails and the details of the technic of insertion vary a great deal and must be tailored according to the anatomy of the medullary canals of the several long bones. Most of these nails are called by the names of the designer.

For fractures of the femoral shaft, the Kuntscher nail (cloverleaf in cross-section; FIG. 2A) and the Hansen-Street (diamond-shaped in cross-section) are the most commonly employed. Although there are several other designs on the market, none appears to offer any advantages over the Kuntscher or Hansen-Street nail and the majority appear inferior.

For fractures of the tibial shaft the Lottes nail (triflanged in cross-section; FIG. 2B) seems to be the most advantageous (p. 163). Other nails used at times in the tibia include the Hansen-Street, Rush and Kuntscher tibial nails.

For fractures of the shaft of the humerus intramedullary nailing is seldom indicated. Several nails or pins have been advocated, including the Rush pin.

For fractures of the bones of the forearm, Rush pins (circular in cross-section; FIG. 2C) are the most generally employed, although they are not perfect in design (p. 89). They are almost too large for the medullary canal of the ulna. A modification of the Rush pin with a rounded instead of a sled-runner point and pins of other designs are available. The new Schneider self-broaching pin appears to offer the advantage that it will broach out the canal to adequate size as it is inserted.

Supplementary Bone-Grafting

Within the past few decades primary bone-grafting has been used increasingly as a supplement to internal fixation of fractures. This use of supplementary bone-grafting has stemmed from several clinical observations. First, it has been established that bone-grafting with multiple chips and strips of autogenous cancellous bone gives a high percentage of union at previous sites of nonunion. Concurrently, the wing of the ilium was recognized as a large reservoir of cancellous bone easily available. Before the days of intramedullary nailing, rigid plating had been employed frequently to obtain adequate reduction of fragments but this method of internal fixation had given a too high incidence of nonunion. When the surgeon selected this method it was natural for him to try to avoid nonunion by the precaution of primary bone-grafting with cancellous bone from the wing of the ilium, particularly for fractures of the tibia and bones of the forearm, where nonunion was not infrequent. It was hoped that primary bone-grafting would catalyze the healing process. Because primary bone-grafting had proved advantageous with plating, it was again natural that it would be extended as a supplement to the internal fixation of fractures with intramedullary nails. It seems reasonable that the bone-grafting procedure is added insurance against nonunion of the fracture and moreover, should speed the rate of union of the fracture allowing for a shorter period of external splinting and a quicker return of normal function.

Technic: Grafts of cancellous bone are best obtained from either the anterior or posterior third of the wing of the ilium at or near the crest. When the open reduction of a fracture to be grafted is performed with the patient lying on the back, the donor site for the grafts is the anterior third of the crest of the ilium, and conversely, if the open reduction is performed with the patient in the prone position, the posterior third of the crest is selected.

The iliac crest is exposed through a slightly curved incision of appropriate length. The fascial origin of the muscles arising from the outer portion of the wing of the ilium is incised and these muscles are stripped subperiosteally. Strips of external cortex of the wing of the ilium may be obtained with a chisel and mallet in either a transverse or vertical direction. When one or more of these strips have been removed, large quantities of cancellous bone may be obtained particularly just beneath the crest itself. Actually, the muscles on the inner side of the crest may be stripped subperiosteally and after the crest has been removed, thin strips containing each cortex with cancellous bone between may be obtained as needed. While it is desirable to preserve the iliac crest, it is not essential and no disability results after suture of the fascial origins of the muscles arising on the inner and outer surfaces of the wing of the ilium over the remaining raw bone. The supply of cancellous bone is almost unlimited and large defects at fracture sites may be obliterated by packing with multiple chips. In bone-grafting of fresh fractures the usual technic is to pack any defects at the fracture site with small chips of cancellous bone and then lay strips about the fracture site in a barrel-stave fashion.

Wound Closure

Proper management of the operative wound after open reduction and internal fixation of a fracture has been achieved includes thorough irrigation of the wound with normal saline as an important preliminary to closure by suture. Forceful irrigation removes small particles of loose and devitalized soft tissue and blood clots and is a significant procedure in the prophylaxis against wound sepsis. In those operations which include supplementary bone-grafting, the wound is usually irrigated prior to placement of the bone-grafts.

Objectives of wound closure include the approximation of severed tissues in layers without excessive tension so as to obliterate dead space within the wound. Sutures should include only small bites of tissue and not strangulate blood supply to contiguous tissues.

Wound closure is carried out with interrupted sutures in both the deep layers and skin. The suture material may be braided black silk or catgut in sizes 00, 000 or 0000 depending on the strength needed. Running sutures are seldom justified, usually only when great speed is desirable as a life-saving measure. Running sutures must always

be of catgut. In open fractures, interrupted silk may be employed if the débrided wound is quite clean but interrupted catgut is preferable when slow wound-healing and perhaps prolonged drainage are anticipated.

Interrupted sutures should be placed in both the fascial layers (occasionally also in muscle layers) and skin sufficiently close together to effect a good approximation of each layer but not so close together as to produce a near watertight closure. Rather, they should be placed far enough apart to permit serum to ooze or be expressed out manually during wound closure and later by the postoperative compression dressing. As a rule, too loose a closure is preferable to too tight a closure. Efforts to suture periosteum are seldom worthwhile.

The use of a compression dressing and elastic bandage support of circulation of the entire extremity is discussed (p. 31) under complications of open reduction and internal fixation. These measures are important supplements to proper closure of the surgical incision.

SPECIAL PROBLEMS OF OPEN REDUCTION

Open Reduction in Children

Open reduction of fractures in children is seldom justified and moreover, except in special instances, it is contraindicated. Blount states that the use of internal fixation in children because closed reduction fails on the first try is the way of the impetuous surgeon.

Open reduction is indicated, however, in a few specific fractures in children. These include a group of fractures around the elbow, such as those of the medial or lateral condyle of the humerus with rotation and significant displacement and fractures of the head and neck of the radius with displacement or severe angulation. Open reduction is also indicated in irreducible epiphyseal separations such as those at the distal end of the femur or distal end of the tibia if the residual displacement is severe after efforts at closed reduction. Open reduction is not necessary for these injuries when the residual displacement is minimal. In those instances where open reduction is performed for fractures in children, internal fixation may not be required. For example, following open reduction for a displaced fracture of the head and neck of the radius in a child, the small fragment is merely replaced in position and no internal fixation is needed and, indeed, is usually contraindicated.

Internal Fixation in Open Fractures

Surgery on the wound of an open fracture is designed to rid it of those factors that predispose to infection—namely, dirt, debris, dead and devitalized tissue and blood clots—and to determine if surgical closure of the open wound is indicated and if so, to close it. In addition a method of management of the fracture must be selected.

Insofar as the fracture is concerned, the same methods of management are applicable in general to open as to closed fractures. In open fractures, however, following adequate débridement of the wound, the question of employing internal fixation must be decided at once. This is a problem which requires expert judgment.

Practically, when the time lag between injury and débridement is not too prolonged, if it seems certain that remaining tissues will survive and the wound can be closed by suture without excessive tension, internal fixation of the fracture through the open wound may be performed with little hesitancy *if* internal fixation would be the treatment of choice had the fracture been closed instead of open. If, on the other hand, factors predisposing to wound sepsis are present, internal fixation is probably too hazardous. In doubtful instances, some other method of management of the fracture should be provided and every effort instituted toward obtaining early wound-healing without infection. If, then, adequate reduction of the fracture has not been obtained and maintained, a delayed or secondary open reduction and internal fixation may be carried out through a healed intact skin envelope with anticipation of success.

In weighing the factors for and against internal fixation of open fracture, the surgeon must remember that internal fixation actually may be of value in minimizing the danger of postoperative infection and in obtaining healing of the open wound. With the fragments in excellent reduction, dead space in which contaminated blood clot could collect is reduced in size or eliminated. The fragments are held in position so that none will displace and protrude between the margins of the open wound, or impinge against the deep surface of the skin overlying the fracture site and produce ischemia and subsequent slough. With the fragments stabilized in reduction by internal fixation, staged procedures designed to keep all cortical bone covered with healthy soft parts and to achieve sound healing of the wound may be carried out.

When internal fixation is used in open fractures, any technic which might further embarrass the arterial supply to the skin margins should be avoided. Metal should not be placed where it might interfere with closure of soft parts over it. Periosteal stripping should be held to a minimum. Because multiple screws and intramedullary nails require minimal periosteal stripping and do not handicap closure of the wound, they are preferable as methods for internal fixation of open fractures.

Fractures Associated with Contiguous Burns

In the event of a new war, fractures associated with contiguous burns may be a typical and common problem. Fitts and others, from experimental work in the dog, postulate that intramedullary nailing might be the best method available for the treatment of certain fractures complicated by contiguous burns. Its chief advantage, as far as the care of the burn is concerned, is that it eliminates external fixation and leaves the burned area free to be treated in any desired manner. The question arises whether this advantage is outweighed by the increased risk of infection resulting from nailing in the presence of an open wound. Does a nailing operation performed through burned skin and leaving a foreign body in the medullary canal predispose to serious infection and delayed healing of either bone or skin, or does the rigid fixation afforded by the nail outweigh the increased contamination of a fracture site as well as the burn and also, the presence of a foreign body?

Doubtless, an operation performed through a contaminated wound increases the risk of infection within the bone, but so does motion at the fracture site. The rigid immobilization obtained by intramedullary nailing may so decrease the risk of active infection that it more than compensates for the operative contamination and the presence of a metallic foreign body. The great advantage of intramedullary nailing over skeletal traction for these injuries is that it allows complete freedom in moving the patient and, therefore, makes early evacuation possible. It also allows earlier ambulation in most instances. In their experimental work on the dog the authors state, "Under the conditions of these experiments in dogs, open reduction and insertion of an intramedullary nail through burned skin did not increase soft tissue or bone infection compared to a control limb immobilized with plaster of Paris. This was true for both open

and closed fractures. The fact that fixation with an intramedullary nail allows the burn wound to be left open resulted in better healing of this wound on the nailed side in practically every instance. In seven dogs of a closed fracture-contiguous burn series, in which both radii and ulnae were fractured, spreading of soft tissue infections from imperfect fracture fixation on the unnailed side led to muscle necrosis, delayed compounding from within and death of the dog. The opposite, nailed side did not become septic and the bone fragments remained stable."

Pathologic Fractures

The advent of intramedullary nailing produced a radical change in the entire outlook of the surgeon and patient toward pathologic fractures of the shafts of long bones, particularly those of the femur. Previously, internal fixation by plates and screws was out of the question, and prolonged periods of recumbency in traction or plaster immobilization were all that could be offered. These methods were usually attended by numerous complications such as decubiti, cystitis, pneumonia, etc. Moreover, deep radiation therapy could be given only under difficulties.

On the other hand, intramedullary nailing of these problem fractures usually eliminates the need for external splinting (or minimizes it), permits appropriate nursing care to prevent complications and allows ideal deep radiation therapy. The burden of proof is on the surgeon who chooses a method other than intramedullary nailing for pathologic fractures of the shafts of long bones. Actually, intramedullary nailing may justifiably be carried out prophylactically in many impending fractures at the sites of metastatic lesions.

CERTAIN COMPLICATIONS OF OPEN REDUCTION OF FRACTURES

Shock

Patients with extensive fractures, both closed and open, may develop the clinical syndrome of shock from loss of blood and extracellular fluid from the circulating blood volume. In open fractures the blood loss is obvious. In many closed fractures, especially those of the femoral shaft, extensive loss of blood into the tissues also may occur but the heavy fascial envelope of the thigh may mask the loss. Before open reduction can be performed, wound shock must be overcome. One often sees written, "Wait until shock is over before

operating." The selection of the word "wait" is a poor one. This should not be a waiting period but a period of vigorous treatment, particularly in replacing the lost blood.

Shock from blood loss may be a serious complication at operation for open reduction of fractures. In fact, if we assume that good anesthesia is being administered and that the patient is not suffering from abrupt adrenocortical insufficiency, shock developing during open reduction is almost always the result of excessive blood loss combined with inadequate blood replacement.

Prior to operation, blood loss through open wounds or into the tissues should be compensated for by adequate blood transfusions and during operation sufficient blood should be given to balance the blood lost during the operation. This is easily underestimated. Fitts and his associates, using the dry sponge-weighing technic of Wangensteen et al., have demonstrated that patients with trochanteric fractures undergoing operation for internal fixation of the fracture may lose as much as 1000 cc. of blood at operation. While blood replacement in the aged must be adequate, Peden and his associates at the Homer G. Phillips Hospital in St. Louis have demonstrated a high incidence of pulmonary edema and myocardial failure associated with a high death rate in elderly patients who were given massive transfusions in an effort to overcome a chronic anemia probably associated with a contracted blood volume. They conclude that while blood replacement should be adequate to compensate for blood loss and to avoid hemorrhagic shock, considerable caution is indicated to avoid the complications which they encountered with preoperative blood transfusions which were given on indications other than acute blood loss.

Operative blood loss may be minimized by good operative technic which includes approaching the fracture sites through fascial planes, ligation of actively bleeding vessels, packing of portions of the operative wound not needed when the actual surgery is going on at a different part of the wound and prompt reduction of the fragments after the fracture site is exposed in order to minimize blood loss from the medullary canals.

Blood loss during open reduction may be minimized in many instances by the use of compression tourniquets. In fact, these should be used wherever they are practicable. A tourniquet may be left in place without release for one and one-half to two hours but if the operation is not complete when that time has elapsed, the wound

should be packed, the tourniquet released for five minutes and then reapplied, preferably after elevation of the extremity. The reapplied tourniquet may then be left in place for 45 minutes to an hour without danger to the extremity. This period of time should be ample for completion of any operation of open reduction and internal fixation of a fracture.

An increasing number of patients are being treated with adrenal steroids. When these patients are subjected to added stress, such as a fracture, their requirement for steroids is increased. The surgeon operating on a patient previously under treatment with steroids may prevent the shock of adrenal insufficiency by properly planning the dosage of steroids before, during and after operation.

Fat Embolism

Fat embolism following fractures is probably more common than is generally recognized. Free fat can be demonstrated in the urine of a high percentage of patients with extensive fractures and also those with extensive soft tissue injuries. Fortunately, the clinical syndrome of fat embolism is not common.

Symptoms and signs of cerebral irritation may be caused by cerebral fat embolism, and symptoms and signs of pulmonary complications may result from pulmonary fat embolism. While investigation to confirm or rule out this diagnosis to explain the complicating symptoms is indicated, no specific treatment for it is known at the present and supportive therapy constitutes all that can be done.

Experimental studies on intramedullary nailing have indicated that considerable fat may be forced through the venous system at the time of open reduction and intramedullary nailing. Maatz showed that fat emboli could be demonstrated routinely in the lungs after intramedullary nailing. Even when all of the long bones in the same animal were nailed, the fat emboli were not manifested clinically. Theoretically, extensive intramedullary nailing, particularly for fractures of the femoral shaft, should have led to an increased incidence of fat embolism. Clinically, this has not been the general experience.

Thrombo-Embolism

Patients in the older age group with fractures of the lower extremities are particularly susceptible to the complication of throm-

bo-embolism. Many of these patients necessarily must remain recumbent in bed for extended periods with some degree of immobilization of the injured lower extremity. At best, exercise of the muscles and joints of the injured extremity is often minimal.

In some ways the open reduction of fractures may enhance the danger of thrombo-embolism. A period of relative hypotension during the operative procedure predisposes to venous stasis. It is possible that the trauma of retractor pull and manipulation of the fragments within the wound may mechanically retard the rate of flow of blood through the veins caudad to the operative field. The pain produced by the incision itself acts as a deterrent to active exercise of the extremity by the patient during the early postoperative period.

On the other hand, open reduction may reduce the chances of thrombo-embolism. With the fragments better stabilized in reduction by internal fixation the patient may be turned in bed frequently and promptly gotten up into a chair. Early active exercises of the joints and muscles of the lower extremities often may be instituted. The injured extremity may be adequately elevated to promote the rate of venous return. Especially in fractures about the hip in the aged, these advantages of open reduction and internal fixation tend to reduce the incidence of thrombo-embolism in comparison with closed methods of treatment.

When open reduction is used, a number of prophylactic measures against thrombo-embolism must be taken. Periods of hypotension during the operation should be minimized by adequate oxygenation, adequate blood replacement and minimal operative trauma. As part of the dressing of the operative wound, compression bandages should be applied from the base of the toes to well above the operative wound. Following operations about the hip the compression bandage should extend in spica fashion about the hip. Wrapping of the extremity on the opposite side with an elastic bandage from the base of the toes to the hip is an added precaution. The extremity which was operated on should be elevated to promote venous return. The ankle should be slightly higher than the knee and this in turn slightly higher than the hip. Particularly, a pillow should not be placed beneath the knee so that it is flexed, permitting the ankle to be more dependent than the knee. Early active exercises of all of the muscles of both lower extremities should be instituted and as

rapidly as possible the patient should be turned frequently in bed and mobilized at least to the sitting position. During the time the patient is in the sitting position, the knees should not be flexed so that the legs and feet hang dependently unless active exercises of the knee and ankle are being carried out almost continuously.

One of us (W. T. F., Jr.) formerly used prophylactic ligation of the superficial femoral veins as a precaution against thrombo-embolism in elderly patients with fractures of the hip but has discarded this procedure because within one week, during the year 1949, two deaths from pulmonary embolism occurred in patients with fractured hips in which ligation of the superficial femoral veins had been performed prophylactically. Subsequently, he has used heparin prophylactically in almost all elderly patients with fractures of the hip. Heparin has been started about 12 hours after operation and given intramuscularly every six hours in a dosage aimed to keep the clotting time (Lee-White method) between 20 and 30 minutes, measured one hour before the time of the next injection. This therapy is continued for 10 days routinely. Since that time no patient with a fractured hip has been shown to die of pulmonary embolism and in no instance did the clinical course indicate that pulmonary embolism was contributory to death. In his experience, complications from the use of heparin have been minimal. Bleeding from the wound has occurred but this has usually been controlled easily. Heparin can be neutralized by the administration of protamine, 1 mg. of protamine for 1 mg. of heparin, if hemorrhage from the wound continues. The other author (O. P. H., Jr.) does not consider anticoagulants indicated as prophylaxis of thrombo-embolism.

Wound Infection

By far the most significant and potentially devastating local complication of open reduction is wound infection. It can be so catastrophic that no precaution against it may be omitted.

Wound infections may be classified as:

1. Invasive infection—a bacterial invasion and destruction of previously living tissue producing a spreading infection with all of the cardinal signs of inflammation (for example, streptococcic cellulitis).

2. Wound suppuration—a collection of purulent material within a wound (abscess formation)—resulting from the septic breakdown

From slight to moderate postoperative elevation of the extremity is indicated to aid venous return through the extremity. The degree of elevation must not be sufficient to hinder the arterial flow to the extremity.

Prophylactic Antibiotics: Antibiotics given systemically in adequate dosage are certainly a deterrent to invasive infection of living tissue by organisms which are sensitive to them. Antibiotics will not sterilize dead and devitalized tissue, including massive blood clot, which remains in a wound and they will not neutralize the proteolytic enzymes in undrained pus. They, therefore, can never be an absolute prophylaxis against wound suppuration.

The use of antibiotics prophylactically is most controversial. One school, perhaps composed of surgical purists, says "never." They contend that if wound infection is to occur it will do so regardless of antibiotic therapy and in the meantime, some organisms in the wound may develop a resistance to that antibiotic so that it will be of no avail if needed later for a real infection. In fact, the emergence of resistant staphylococci or "hospital or house staph" they attribute, at least in part, to the use of prophylactic antibiotics. The members of this school contend that antibiotics may mask a latent deep abscess which will present itself later, all the while causing the unnecessary destruction of previously living tissue in the depths of the wound. They also contend that antibiotics give a false sense of security which predisposes to sloppy technic.

Proponents of prophylactic antibiotics, the other school, explain their position as follows: Some bacterial contamination takes place in every operation. These bacteria may come from the exhaled air of the operating team, particles of dust in the room air, hair follicles or skin pores in the field of operation or from inadvertent breaks in aseptic technic. The bacteria may be capable of invasive infection of living tissue or of producing wound suppuration. Prophylactic antibiotics, even though given without benefit of test for sensitivity, should be strong deterrents to invasive infection and may prevent wound suppuration particularly if the operative technic has been carefully carried out and the pabulum of wound suppuration has been kept to a minimum.

Instances in which an abscess has appeared many weeks or months after operation have been attributed to the delaying effect of prophylactic antibiotics. In these instances, perhaps an invasive infec-

and venous drainage. Above all, it must be free of furuncles and other skin lesions which could harbor infection. The post-traumatic edema must not be so great as to jeopardize closure of the operative wound because of excessive tension.

Operative Precautions: *Strict attention to the many details of* good technic during the operative procedure will pay dividends in a reduced incidence of wound infection. Skin preparation should be thorough over a large field. Draping of the extremity must be carefully and precisely carried out. Aseptic technic must be continually guarded. Devitalization of tissue due to the trauma of the surgery must be minimized; this means avoiding clamping and ligating large fragments of tissue and minimizing the trauma of retractor pull. Arterial supply of muscles should be safeguarded. Hemostasis must be adequate to avoid a postoperative hematoma in the depths of the wound. Any tags of devitalized or badly traumatized soft tissue should be trimmed and discarded after internal fixation of the fracture has been completed. At the conclusion of the procedure thorough irrigation of the wound depths and crevices is indicated to flush out small blood clots and bits of devitalized tissue. The operative wound should be closed so as to obliterate dead space but loose enough to allow for egress of the unavoidable serum and blood exudations from the depths of the wound especially during the first few hours after the operation. Small dependent drains of rubber tissue, perhaps through a stab incision, frequently may be used for the first 24 to 48 hours to insure drainage of serum and blood from an unobliterable dead space in the wound depths.

Postoperative Precautions: All of the factors outlined above under measures to prevent shock and thrombo-embolism are also strong deterrents against a postoperative wound infection. The compression dressing helps to obliterate dead space and wrapping of the extremity which was operated on from the base of the toes or fingers to above the site of the operative incision minimizes edema about the wound and, therefore, tends to prevent excessive tension on the sutured wound margins, a situation which could lead to ischemia and resulting necrosis and subsequent wound infection. Compression bandages as just described should be considered as part of the dressing following every open reduction and internal fixation. However, when a plaster cast is applied for immobilization, the cast serves as the compression bandage.

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Instances in which an abscess has appeared many weeks or months after operation have been attributed to the delaying effect of prophylactic antibiotics. In these instances, perhaps an invasive infec-

tion was prevented and probably the development of the abscess was retarded by antibiotics. If this be true, it is reasonable that prophylactic antibiotics may in other instances be effective in preventing wound suppuration. As an additional point in favor of prophylactic antibiotics, those who favor them contend that they may prevent urinary and pulmonary complications, particularly in the older age groups.

Due consideration of the viewpoints of both schools leads to the conclusion that prophylactic antibiotics are indicated following open reduction and internal fixation in all originally open fractures, following large and prolonged operative procedures in which the operative wound necessarily remains open an extended period of time, after procedures in which a definite break in sterile operative technic was discovered and in the older age groups if for nothing more than to protect against urinary and pulmonary infections. When it is anticipated that prophylactic antibiotics will be used postoperatively, it appears advisable actually to administer antibiotics immediately prior to operation in dosage sufficient to gain a protective blood level.

Almost all serious wound infections following the open reduction of fractures are caused by the *Staphylococcus aureus.* When antibiotics are used prophylactically, the surgeon should select those shown to be most effective against the *Staphylococcus aureus* organisms prevalent in the hospital at the time.

Management of Postoperative Wound Suppuration Following Open Reduction and Internal Fixation of Fractures: The treatment of this complication is primarily surgical. In the operating room, under anesthesia, the wound should be opened widely by removal in most instances of all of the superficial and deep sutures. Cultures of the material from the depths of the wound should be taken and sensitivity tests should be run. When the indicated antibiotic has been determined, this should be administered in adequate dosage. Until this has been determined the surgeon should give the antibiotics most effective against the *Staphylococcus aureus* prevalent in the hospital at the time. Any tags of dead and devitalized tissue should be excised. The wound should be irrigated thoroughly.

The wound should be left open to obtain better drainage but frequently, in addition, dependent drainage to the wound depths should be established through a stab or counterincision and maintained for several days.

In many instances, the opened operative wound may be closed by delayed suture four or five days after it has been opened. If the wound margins fall together with a good compression dressing, closure by suture is really of no significance as the wound can heal promptly if the infective process has been eliminated. On the other hand, if the open wound tends to expose bony cortex, tendon, cartilage or metallic internal fixation, adequate closure by suture to cover these structures is indicated.

The question of whether to remove an internal fixation device under these circumstances has been debated. Under most circumstances it is so important to have the bone well stabilized when infection is present that it is best to leave the internal fixation undisturbed. The metal may prove to be a deterrent to wound-healing but, at this particular time, the stability it provides is most advantageous not only in maintaining reduction of the fracture but in combating the septic process by providing thorough immobilization of the fragments. If wound-healing is not obtained within a reasonable period of time, the matter of removal of metal may be reconsidered. Provided sepsis is controlled it should remain in place until enough bony union has taken place to stabilize the fracture.

Nerve or Vascular Injury

An injury to a major peripheral nerve or artery during operation for open reduction and internal fixation of a fracture is an avoidable complication. Occasionally, minor sensory nerves or arteries may be sacrificed intentionally in the interest of improved exposure of the fracture but as a rule even these should be safeguarded. An intimate knowledge of the anatomic relationships of nerves and arteries is a fundamental prerequisite to the selection of the method of open reduction and internal fixation. A review of the anatomy of the part by the surgeon prior to the operation (or even during it by means of a book of anatomy on a nearby stool) is not an admission of ignorance but, on the contrary, is an index of thoroughness and full interest in the patient's welfare and is to be commended.

For the indicated treatment, if injury to either of these structures inadvertently takes place, reference should be made to standard texts and current literature on the management of injuries to peripheral nerves and blood vessels.

Delayed Union and Nonunion

In spite of all precautions in selection of cases for open reduction and internal fixation and the most precise technics, some fractures will later show delayed union or nonunion. Even so, this incidence can be held to a minimum by adherence to the principles, technics and precautions to be covered in succeeding sections in this monograph. To ignore these will certainly lead to high incidences of delayed union and nonunion.

The anticipated time at which to expect union of a fracture after open reduction and internal fixation varies with different fractures. If the upper limit of this period has been reached or exceeded without roentgenographic evidence of union of the fractures, some additional surgery may be advisable. All too often a state of nonunion is allowed to go on and on to the detriment of the patient because nonunion is either not recognized or its presence not accepted. This is particularly true when the internal fixation is providing so much stability that signs of nonunion on physical examination are masked. The nonunion must be recognized and appropriate action taken (usually bone-grafting and often replacement or changing of the internal fixation). To delay excessively risks fatigue-breaking of the internal fixation device or devices as result of long-continuing strain.

Symptoms of nonunion after open reduction and internal fixation include persistent low-grade pain at the fracture site and limited function of the part. Signs include tenderness at the fracture site and pain at the same location on rotary and angulatory strain. Confirmatory evidence is gained by roentgenograms. Nonunion may be obscured particularly by exuberant callus about fragment ends but actually not bridging them. Slightly overexposed roentgenograms are preferable when assessing the status of union of a fracture.

2 *Fractures of the Upper Extremity*

FRACTURES ABOUT THE SHOULDER

FRACTURES ABOUT THE SHOULDER for which open reduction and (usually) internal fixation may be indicated include fracture-dislocations of the shoulder, fractures of the surgical neck of the humerus, fracture-epiphyseal separations of the proximal humerus, and, rarely, fractures of the clavicle.

Fractures of the Proximal Humerus

Fractures of the proximal end of the humerus which require primary open reduction are usually complications of dislocation of the shoulder. These include dislocation of the humeral head with a displaced fracture of the surgical neck of the humerus (fracture-dislocation) and dislocation of the humeral head with a fracture of the greater tubercle of the humerus associated with rather massive tear of the musculotendinous cuff of the shoulder. Open reduction for fractures not associated with dislocations is usually performed as a secondary procedure after unsuccessful application of another method. Such fractures include badly displaced fractures of the surgical neck of the humerus and fracture-epiphyseal separations with marked angulation in adolescents.

Dislocation of the Shoulder Associated with a Fracture of the Surgical Neck of the Humerus (Fracture-Dislocation of the Shoulder): An overwhelming majority of fracture-dislocations of the shoulder require open reduction with or without internal fixation of the fracture. Rarely manipulative efforts will lead to replacement of the humeral head into articulation with the glenoid and, if so, the fracture of the surgical neck of the humerus usually is reduced simultaneously. The chances of successful efforts at closed reduction are so poor, however, that the surgeon and the operating room should be ready to proceed immediately with open reduction under the same anesthesia when the closed attempt is made.

Technic: Either of two standard surgical approaches to the shoulder gives adequate exposure for open reduction of fracture-

dislocations of the shoulder. These are the anterior-medial approach (Thompson and Henry) which we prefer and the trans-acromial approach (McLaughlin). Both approaches are best carried out with the patient in the semisitting position with a flat sandbag or folded sheet beneath the body of the scapula.

Anterior-Medial Approach (Thompson and Henry; FIG. 7): The skin incision extends from the outer end of the clavicle along its anterior margin to a point about over the most medial clavicular origin of the deltoid muscle. It then turns downward along the anterior-medial margin of this muscle to a point a short distance above its insertion. As the incision is deepened, the cephalic vein is identified

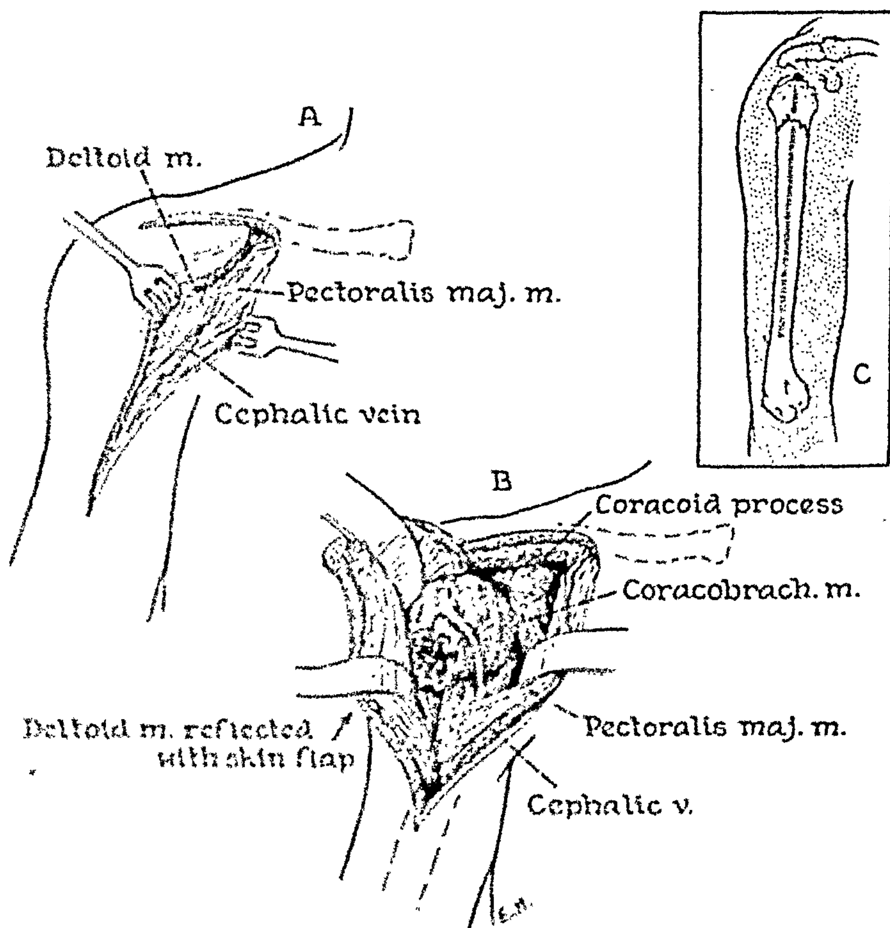


FIG. 7. Anterior Approach to the Shoulder. (A) Skin incision follows along the deltopectoral groove and anterior border of the clavicle. (B) Skin flap and deltoid muscle are reflected, exposing an overriding fracture of the surgical neck of the humerus. (C) The fracture is reduced and stabilized with an intramedullary pin.

in the deltopectoral groove. The anterior-medial margin of the deltoid muscle is separated from this vein leaving a few fibers with the vein if this seems indicated to protect it. The clavicular origin of the deltoid muscle is severed leaving a short stump of muscle attached to the clavicle to facilitate reattachment of the deltoid as part of closure of the wound. The anterior half of the deltoid muscle may now be reflected laterally so as to expose the structures immediately covering the shoulder joint and the coracoid process. The raw surface of the proximal end of the shaft of the humerus is easily identified.

After reflection of the deltoid muscle, the humeral head in some instances may be guided back into joint through the rent in the capsule with an instrument or the gloved finger. Such near blind reductions however risk damage to axillary vessels or cords of the brachial plexus. More often, the tip of the coracoid process must be osteotomized to permit medial retraction of the biceps and coracobrachialis muscles. A drill hole should be made into the body of the coracoid before it is severed to facilitate reattachment with a screw as part of closure of the wound. Not infrequently when the line of fracture is near the articular surface, the subscapularis tendon must be severed close to its insertion to obtain full exposure.

With adequate exposure the humeral head is usually guided into the glenoid cavity without difficulty. In most instances, the fracture of the surgical neck is reduced simultaneously. Usually internal fixation of the fracture is not necessary and the injury is treated postoperatively as if it had been only a displaced fracture of the surgical neck of the humerus requiring manipulative reduction (FIG. 8). In others, some stabilization of the fragments appears indicated. Loops of malleable stainless steel wire may be placed through adjacent portions of the cortices of the major fragments or an intramedullary pin may be inserted through the upper fragment and down the canal of the lower fragment. Occasionally, the Nicola technic for recurring dislocation may be advantageous. The tendon of the long head of the biceps is divided at a point below the level of the fracture; the proximal end is drawn through a drill hole beneath the bicipital groove in the proximal fragment and the proximal portion of the distal fragment and then resutured to the distal portion of the tendon. If a fragment of greater tuberosity containing the insertion of most of the musculotendinous cuff has been separated and is re-



Fig. 8—*Fracture-Dislocation of Shoulder.* (A) Anterior-posterior view of left shoulder showing that the dislocated head of humerus lies subcoracoid (arrows point to shadow of dislocated head) while the stump of shaft lies against the glenoid. Efforts at closed reduction were unsuccessful; under the same anesthesia, open reduction was carried out (see text for technic). When the humeral head was replaced in the glenoid, the fracture of the surgical neck was reduced simultaneously. The arm was immobilized against the chest wall in a sling and modified Velpeau bandage for two and one-half weeks; then pendulum exercises were initiated. (B) Anterior-posterior view five weeks later showing same union of the fracture. At open reduction the tip of the coracoid process was severed to permit better exposure. It was replaced and held by the screw. The functional result was excellent.

tracted, it must be brought down into position and fixed by screw, loops of wire or suture (see below).

As part of wound closure, each of the severed structures is repaired. If the subscapularis tendon has been severed, it is accurately sutured. The tip of the coracoid process is reattached either by suture or a screw. Reattachment with a screw is facilitated by the preparation of the drill hole prior to osteotomy of the coracoid. The clavicular origin of the deltoid is reconstituted and the remainder of the wound is closed in a routine manner.

Trans-Acromial Approach (McLaughlin): The skin incision passes across the top of the shoulder beginning at a point along the posterior margin of the acromion about ½ inch lateral to the acromioclavicular joint and extending forward to a point no more than 2 inches below the anterior margin of the acromion. The incision is deepened, the fascia over the deltoid muscle is incised and

the anterior fibers are split. In order that the branches of the axillary nerve may be protected, the deltoid fibers are never separated more that 4 cm. below the anterior margin of the acromion. The deltoid origin may be detached from the anterior margin of the acromion (leaving sufficient soft tissue on the latter to permit repair). For adequate exposure for open reduction of a fracture-dislocation of the shoulder, however, osteotomy of the acromion is usually necessary. The line of osteotomy is at about the junction of the inner and the middle thirds of the acromion and leaves the stump of the acromion slightly wider posteriorly than anteriorly. Lateral retraction of the deltoid muscle including the lateral portion of the acromion usually provides adequate exposure for replacing the humeral head into articulation with the glenoid and for internal fixation of the fracture of the surgical neck of the humerus (p. 44) if this seems indicated.

At the time of wound closure, the outer portion of the acromion is excised and discarded. The deltoid muscle is reattached firmly to the remaining portion of the acromion.

Dislocation of the Shoulder Associated with a Fracture of the Greater Tubercle of the Humerus: In the majority of dislocations of the shoulder, a fragment consisting of greater tubercle, if present, follows the humeral head into an inferior position and remains fairly close to its normal position. When the dislocation is reduced by manipulation, which usually is accomplished easily, the fragment, as a rule, goes into excellent reduction. In some instances the prereduction roentgenogram will show the fragment of greater tubercle widely separated. It may remain near the acromion or partially follow the head but remain displaced laterally some distance from its normal location. Either position indicates a complete rupture of the periosteum of the humerus along the inferior portion of the fracture of the greater tubercle and some tear of the musculotendinous cuff of the shoulder. In these situations, open fixation of the fragment of the greater tuberosity with precise repair of the torn soft tissues is indicated. Even if the fragment should drop into excellent position when the humeral head is replaced in the glenoid, barring specific contraindications, internal fixation is still indicated as this should lead to earlier and better return of function of the shoulder.

Technic: Adequate exposure may be obtained by either the anterior-medial (p. 40) or the trans-acromial (p. 42) approach.

With the former, reflection of the deltoid is the only portion of this approach which is necessary and with the latter, osteotomy of the acromion usually may be avoided.

Following adequate exposure of the proximal end of the humerus through the selected operative incision, the fragment of greater tubercle is pulled down into precise reduction and stabilized with one or two screws depending on its size. The tears in the periosteum and musculotendinous cuff are then repaired by interrupted heavy silk sutures. Occasionally, in order to achieve excellent reattachment of a portion of the musculotendinous cuff, mattress sutures through parallel drill holes in the upper humerus may be employed. This is similar to the usual technic for repair of a torn musculotendinous cuff of the shoulder.

Fractures of the Surgical Neck of the Humerus: A great majority of fractures of the surgical neck or proximal portion of the humerus either require no reduction or are readily brought into good reduction by closed efforts. Fortunately, some displacement may be accepted, and indications for open reduction, therefore, are rarely encountered. For practical purposes, about the only absolute indication for operation is when the fragments are completely separated and overriding with the proximal end of the shaft displaced well into the axilla and possibly encroaching on axillary vessels or the brachial plexus and this hazardous position cannot be overcome by manipulative efforts at reduction. In other fractures, open reduction may be desirable merely to gain acceptable apposition of the fragments (FIG. 9).

Technic: Adequate exposure for open reduction may be obtained by either the anterior-medial (p. 40) or trans-acromial approach (p. 42). The former seems preferable because it may be extended easily around the acromion with section of the origin of the deltoid from its posterior surface or farther down the arm if additional dissection and exposure are required.

After adequate exposure has been achieved, to obtain reduction of the major fragments is usually not difficult. At times the biceps tendon will be found between the fragments and presumably to have blocked efforts at closed reduction. At open reduction, this is easily retracted so that the fragments may be brought into reduction.

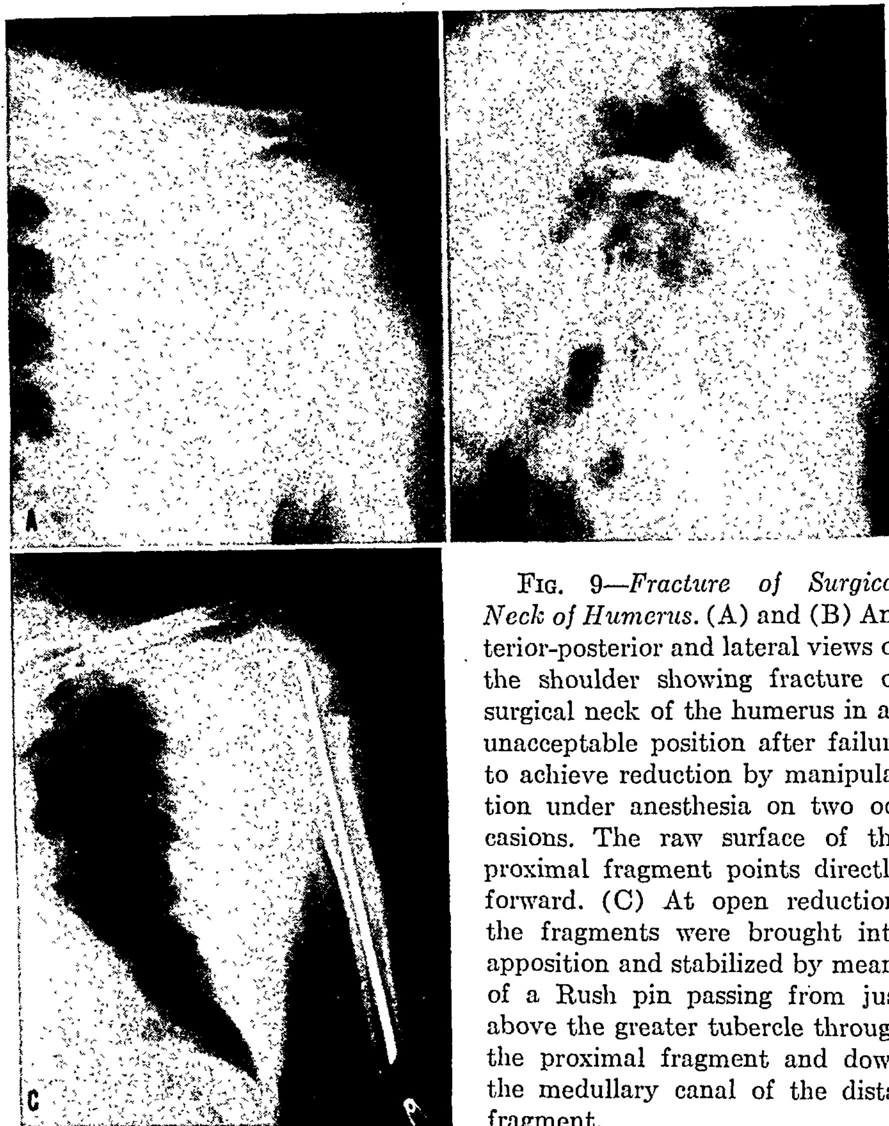


FIG. 9—*Fracture of Surgical Neck of Humerus.* (A) and (B) Anterior-posterior and lateral views of the shoulder showing fracture of surgical neck of the humerus in an unacceptable position after failure to achieve reduction by manipulation under anesthesia on two occasions. The raw surface of the proximal fragment points directly forward. (C) At open reduction, the fragments were brought into apposition and stabilized by means of a Rush pin passing from just above the greater tubercle through the proximal fragment and down the medullary canal of the distal fragment.

With these injuries, internal fixation so as to provide real stability is seldom achieved. In some instances, no internal fixation material will seem indicated. In some, one or more screws or loops of stainless steel wire may be judiciously inserted so as to hold the fragments in the best obtainable position. In others, an intramedullary pin or the Nicola procedure with the biceps tendon as described under fracture-dislocations of the shoulder (p. 41) may be selected.

Fracture-Epiphyseal Separations of the Proximal End of the Humerus: Fracture-epiphyseal separations of the proximal humerus, most frequently encountered in teen-age boys, usually do

not require open reduction. Some displacement or angulation may be accepted with the anticipation that the deformity will be corrected by growth processes and the functional result in the end will be excellent. When the displacement is enough to require reduction, manipulative efforts are likely to achieve a satisfactory reduction. If not, open reduction and usually internal fixation must be carried out.

At operation the proximal fragment will usually be found to contain the head, the epiphyseal plate and a large V-shaped piece of bone distal to the cartilage plate. Adequate exposure is usually provided by the anterior-medial approach to the shoulder joint (p. 40). Often very little deltoid origin must be removed from the clavicle. When the fragment ends are freed, reduction usually comes easily. Stabilization is obtained by one or two screws passing through the V-shaped piece of cortical bone of the proximal frag-

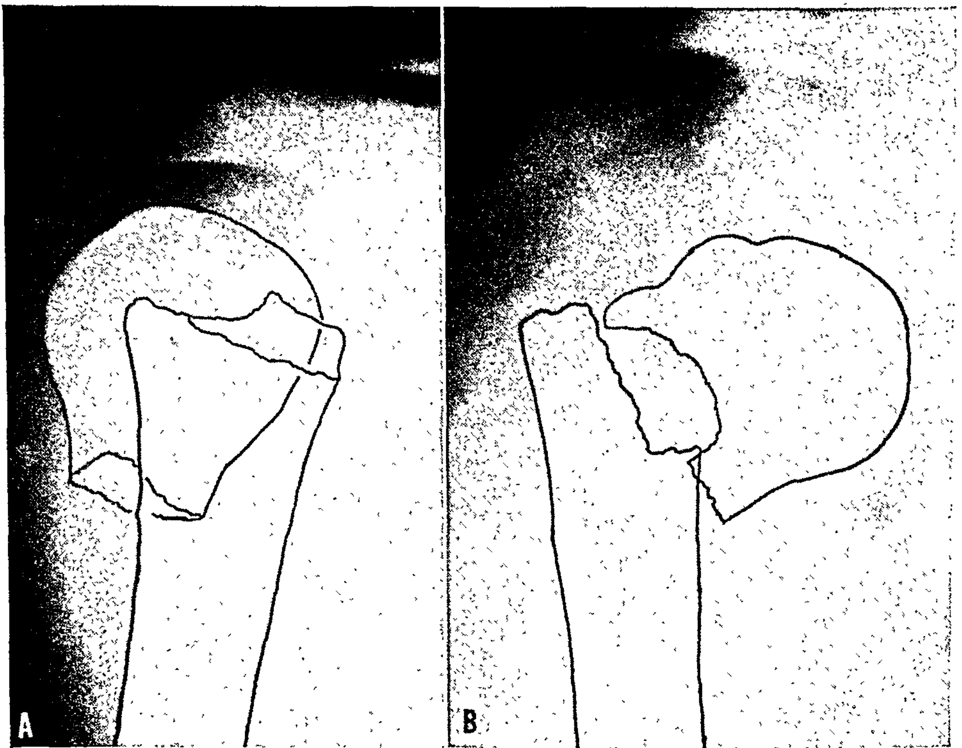


FIG. 10—*Fracture-Epiphyseal Separation of the Proximal Humerus.* (A) and (B) Anterior-posterior and lateral views (retouched by artist for clarity) showing badly displaced fracture-epiphyseal separation of proximal humerus in a 16 year old boy. Efforts at closed reduction were unsuccessful.



FIG. 10—(C) and (D) Anterior-posterior and lateral views after open reduction and internal fixation of the subepiphyseal triangular fragment of bone to the shaft by two screws.

ment into the cortex of the proximal end of the distal fragment (FIG. 10).

Postoperative Immobilization: A sling and swath type of bandage which splints the extremity against the chest wall provides the best form of postoperative immobilization following open reduction of all fractures and fracture-dislocations about the proximal end of the humerus. The duration of immobilization must vary according to the stability obtained with internal fixation. If this has not really stabilized the fragments or if no internal fixation was employed, three to four weeks of immobilization will be necessary. When the fragments have been stabilized so that the reduction will not be lost even if postoperative immobilization were omitted, then the latter may be discontinued when the operative incision is healed in order that appropriate exercises may be instituted.

Pitfalls and Precautions

1. Do not traumatize the cords of the brachial plexus in vain efforts to achieve closed reduction of a dislocated humeral head or a fracture of the proximal humerus.
2. Have adequate assistance for all operations about the shoulder. Experience shows that one assistant will be occupied a great deal of the time in holding and manipulating the arm.
3. At operation, gain adequate exposure through careful step-by-step dissection. Safeguard the nerve supply to the anterior portion of the deltoid muscle.
4. In operations for fracture-dislocations of the shoulder, reduce the dislocated head of the humerus before attempting to reduce the fracture.
5. Make certain that the reduced fracture is stable so that redisplacement of the fragments will not occur if internal fixation is to be omitted.
6. Always repair accurately any associated rupture of the musculotendinous cuff.

Fractures of the Clavicle

Fractures of the clavicle as a general rule are managed by closed reduction because this method gives excellent results in the overwhelming majority of cases. The burden of proof as to the indication is on the surgeon who employs open reduction and internal fixation for this injury. Even so, occasionally it may be justifiable.

One of several rare situations may lead to the selection of the operative method for these injuries. These potential indications include marked separation and displacement of fragments with impending penetration of the skin; the necessity for perfect reduction in order to obtain the best possible cosmetic end-result (when an operative scar seems preferable to a bony prominence at the site of fracture); the desire to avoid encumbering splinting and to permit continuing active use of the extremity as in professional athletes. While considering the operative method for fractures of the clavicle, it should be kept in mind that the thin skin over the clavicle predisposes to faulty wound-healing and wound infection which could be catastrophic.

Technic: In those instances in which open reduction and internal fixation are chosen, the technic illustrated in FIGURE 11 is preferable to other methods. The procedure may be carried out through a relatively short incision and with minimal periosteal stripping. The pin must be large and strong enough to stabilize the fragments and withstand the hanging weight of the upper extremity without bending or breaking. Preferably, a pin is used which is threaded part way as a precaution against wandering. It must be inserted without distraction at the fracture site. The outer end of

the pin should project several millimeters from the cortex of the clavicle but be buried beneath the skin. After union of the fracture as shown by roentgenograms (usually six to eight weeks) the pin must be removed. This may be carried out under local anesthesia through a short incision over the outer end of the pin.

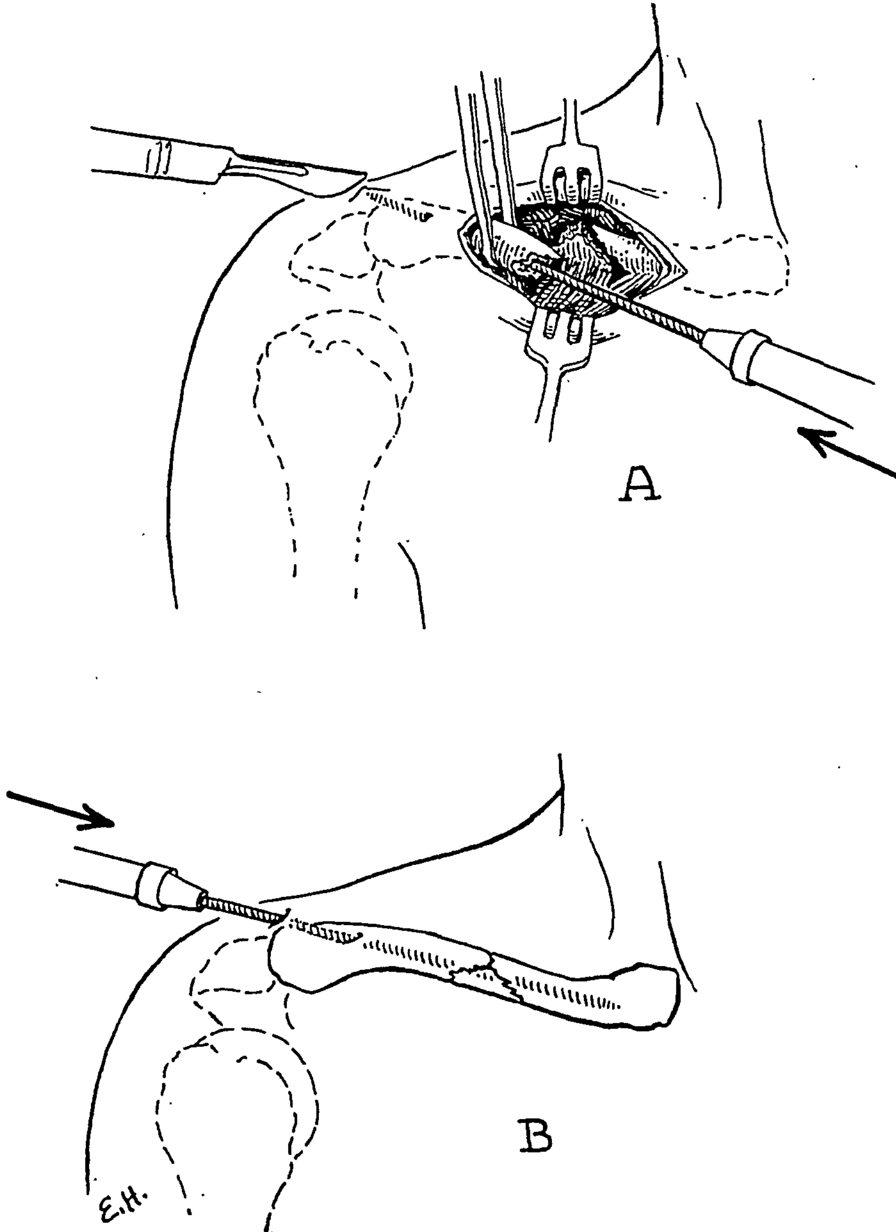


FIG. 11—Intramedullary pinning of a comminuted fracture of the middle third of the clavicle.

Pitfalls and Precautions

1. Make certain that open reduction and internal fixation offers a real advantage to the patient before employing this method.
2. Make the skin incision at the fracture site parallel to but just below the clavicle and then retract the skin upward rather than over the prominent subcutaneous portion of the bone. The incision just below the clavicle is likely to heal better.
3. Make certain that the fragment ends are in firm contact and not distracted by the intramedullary pin.
4. Do not remove the pin until there is solid bony union at the fracture site.

FRACTURES OF THE SHAFT OF THE HUMERUS

The great majority of fractures of the shaft of the humerus respond most satisfactorily to a nonoperative method of management, usually a hanging cast. Under certain situations, however, open reduction and internal fixation may be indicated provided the contour of the fracture will permit an adequate degree of fixation of the fragments. These indications may be classified as:

1. Failure to obtain satisfactory apposition and alignment of fragments of the humerus by closed methods. In this connection it must be pointed out that many fractures of the humerus go on to solid union with only minimal apposition (at times actual overriding) of the fragments. Others, however, show wide displacement of fragments which cannot be overcome by closed methods and are best managed by open reduction and internal fixation.

2. The presence of injuries to other parts of the body which preclude management of the fracture of the humerus by hanging cast or even balanced suspension traction; injuries for example, which may require transporting the patient to the operating room repeatedly or require that the patient be turned frequently in bed.

3. Signs on physical examination indicating complete loss of function of the radial nerve complicating a fracture displaced (or presumably having been displaced) so that end-to-end contact of the fragments has been lost. It is true that function of this nerve will return spontaneously in most such instances. On the other hand, the operative attack permits a nerve caught between the fragments or over the end of a fragment to be released, the fracture to be stabilized in reduction so the nerve will not again become caught and an accurate appraisal of the extent of damage to the nerve (torn, partially or completely, or merely contused). This information may save several months of futile watchful waiting for return of function of the nerve. As a rule definitive repair of a

severed nerve is best postponed until a later staged operation at a time when some union of the fracture has occurred and wound conditions are better for neurorrhaphy.

Technic: Actually, none of the several available methods of internal fixation lends itself ideally to fractures of the humerus. Of course, a long oblique fracture may be stabilized adequately by multiple screws but fractures with this contour seldom come to open reduction because they do so well by a hanging cast. Plating with standard plates risks nonunion (p. 3) or with a slotted plate, postoperative distraction at the fracture site. The hanging position of the arm predisposes to some postoperative distraction regardless of the type of postoperative immobilization. Intramedullary nailing frequently fails to control rotation at the fracture site. This method, however, is the one of choice for segmental fractures. When open reduction and internal fixation seems indicated one or a combination of these methods must be selected despite the shortcomings of each for fractures of the humerus.

The entire shaft of the humerus may be exposed as illustrated in FIGURE 12. The portion of this incision is utilized which will adequately expose the fracture at hand. The radial nerve should be located and protected. Fragment ends are freed and brought into apposition, and then a decision must be made as to the preferable type of internal fixation.

Plating or fixation with multiple screws is carried out by the appropriate standard technic (pp. 11 and 18; FIG. 13). Screws should be inserted in a direction which places the tips well away from the radial nerve.

Intramedullary nailing may be carried out with either of the nails or pins available for the humerus. The Rush pin, the most commonly employed, is usually inserted from the region of the greater tubercle through a separate short incision. The on-going tip is visualized as it reaches the lower end of the proximal fragment; then the fracture is reduced and the nail advanced on down the canal of the distal fragment into the lower one-third of the humerus. A small triflanged Lottes-type nail or a Hansen-Street diamond-shaped nail may be inserted in the same manner or retrograde from the intercondylar region through a short posterior incision over the lower end of the humerus. Either of these nails actually provides better control of rotation at the fracture site but

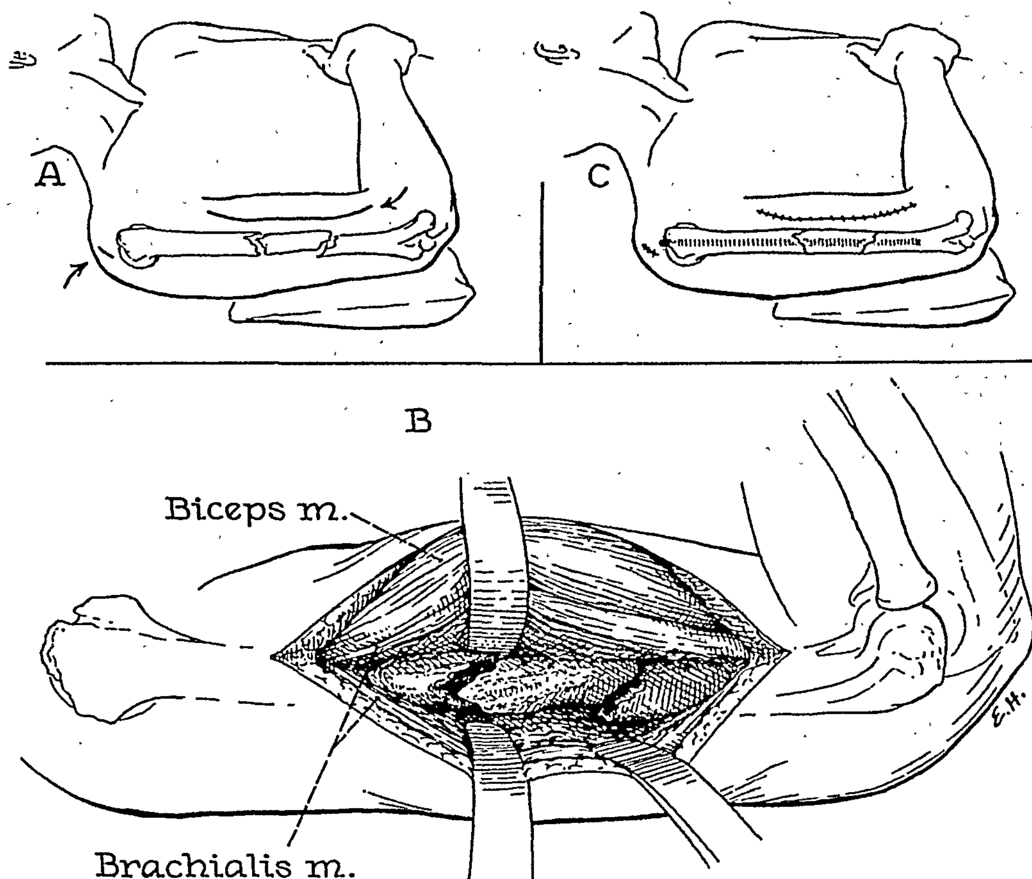


FIG. 12—*Exposure of the Shaft of the Humerus through the Standard Anterolateral Incision.* (A) The line of the skin incision. (B) Viewed from the superior aspect. The double fracture of the humerus has been exposed. Note that the Brachialis muscle has been split. The lateral portion has been reflected, carrying with it the radial nerve. (C) The fragments have been stabilized with an intramedullary pin.

is more difficult to insert and can split the cortex of either fragment. When the retrograde technic is employed, the nail must be long enough to extend to within ¾ inch of the articular surface of the humeral head. As a supplement to intramedullary fixation, a plate, one or more screws or even loops of malleable wire through adjacent cortices of each fragment may be valuable in preventing rotation and postoperative distraction of the fragments.

Primary Bone-Grafting: Since ideal internal fixation of fractures of the humerus is often difficult to achieve, nonunion is more than a remote possibility. Moreover, the middle third of the humerus has always been a fairly frequent site of nonunion with all methods of management. Such a predisposition to this complication may be

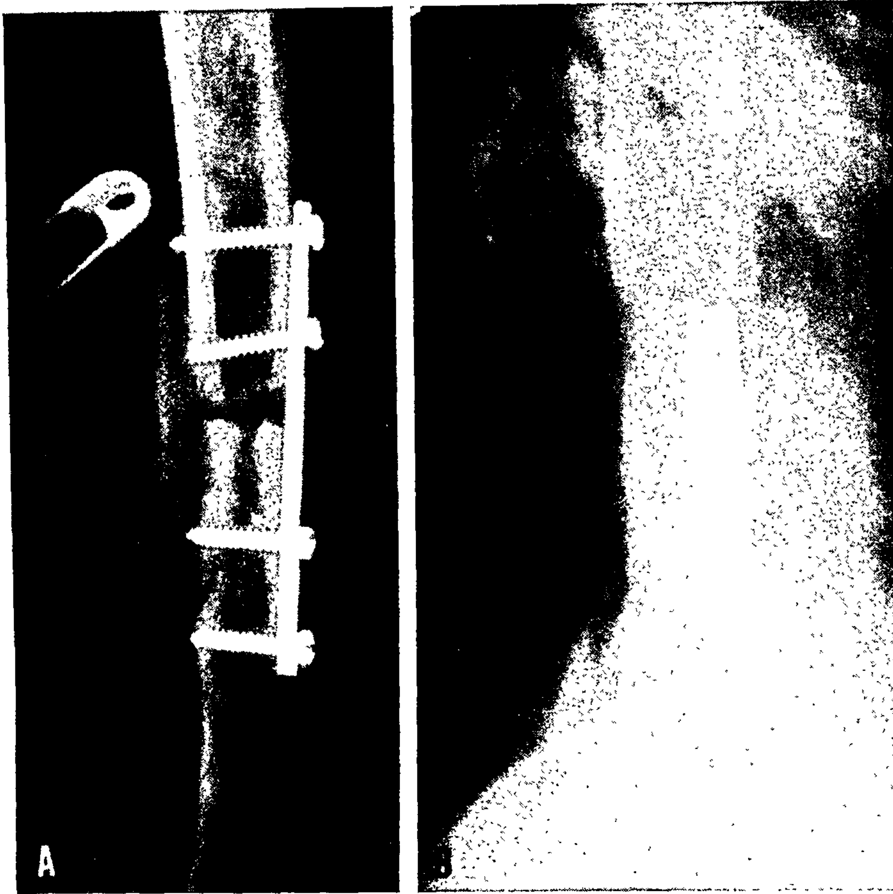


FIG. 13—*Fracture of Shaft of Humerus.* (A) and (B) Anterior-posterior and lateral views showing nonunion of fracture of shaft of humerus stabilized with a slotted plate and screws after fracture site was packed with chips of cancellous bone. Strips of iliac bone were laid across the fracture site in barrel-stave fashion. The small gap at the fracture site seen in the anterior-posterior view would be unacceptable in a primary plating of a fracture of the humerus. It is undesirable here but was unavoidable and the fracture site was filled with cancellous bone chips.

minimized by primary bone-grafting with cancellous bone from the wing of the ileum. Chips and strips may be packed in and around the fracture except at a point where they could encroach on the radial nerve.

Postoperative Immobilization: Some method of immobilization to protect the internal fixation is necessary even though splinting of the humerus is difficult to achieve. At times a hanging-type cast may be employed if the internal fixation is certain to prevent distraction at the fracture site. A shoulder spica in some instances may be selected but these are difficult to apply snugly and postoperative decrease in swelling leaves them even looser. A loose shoulder spica

may place more leverage on the fracture site than no cast at all. In the majority of instances the best postoperative immobilization is that provided by a sling and swathe type of bandage which splints the extremity against the chest wall. The extent and duration of immobilization must vary with the type of fracture, the means of internal fixation employed and the progress of union as determined by serial roentgenograms.

Pitfalls and Precautions

1. Safeguard the radial nerve throughout the operative procedure. Locate, identify and usually free and retract it. Avoid stretch trauma.
2. Make certain the fragments are brought into firm contact and fixed in a way to prevent subsequent distraction.
3. Consider primary bone-grafting as a means of reducing the incidence of non-union.

FRACTURES ABOUT THE ELBOW

Fractures About the Elbow in Adults

Supracondylar and T-Fractures: Many supracondylar and T-fractures of the distal portion of the humerus may be managed adequately by either closed reduction and immobilization, traction as provided by a hanging cast or balanced suspension skeletal traction. A significant number of these injuries, however, cannot be reduced by such nonoperative measures and the more severe the displacement and comminution, the less likely that closed methods will be effective. Precise reduction of the condylar fragments is necessary to restore the lower articular surface, the olecranon fossa posteriorly and the coronoid and radial fossas anteriorly of the lower end of the humerus. If this restoration of anatomy is not achieved, rather marked restriction of motion in the elbow is likely to follow. Open reduction and internal fixation of these injuries, therefore, is frequently indicated.

Indications for primary open reduction should be recognized and the operative procedure carried out promptly rather than attempt reduction by closed measures which are doomed to failure. Delay in operation permits the rather tremendous swelling to develop which is characteristic of injuries about the elbow when fractures are not promptly reduced. Such swelling can further delay the operative intervention and thereby prejudice the end-result. Barring specific contraindications, systemic or local (p. 6), open reduction

of irreducible fractures of the lower end of the humerus should be carried out as an emergency procedure. As a rule, the more severe the comminution and distortion of the lower articular surface of the humerus, the more the demand for operative treatment.

Technic: A successful open reduction of fractures of the lower end of the humerus depends in a large measure on the surgical exposure. The best exposure is provided by the posterior incision as described by both Campbell and Van Gorder which is illustrated in FIGURE 14. Van Gorder points out the advantages of the posterior approach to the elbow as follows: "(1) It affords a more adequate exposure of the broken parts. (2) It allows more freedom in the use and selection of metal fixation. (3) It involves the dissection of soft parts that contain no large vessels or important nerve structures (the ulnar nerve having been previously identified and gently retracted). (4) It is the only approach that gives a clear view of the involved articular surfaces and joint line." Speed and Knight point out that an adequate assortment of Kirschner wires both threaded and unthreaded, wood-type screws, malleable wire and ordinary plates and screws must be available as the type of internal fixation to be used cannot be determined until the entire fracture site has been exposed. A Webb tibial bolt should also be available as this at times may be invaluable.

When the entire posterior approach as illustrated has been developed and the fracture is exposed, the split condyles of the humerus are forced into apposition, any comminuted fragments of articular surface being impacted into position unless they are so small as to indicate removal. The condyles are fixed in their position by either a Webb bolt, threaded wire or screw inserted transversely. The internal fixation should be started from the ulnar side and directed toward the radial side as a precaution against injury to the ulnar nerve. The transfixion device must penetrate through the cortex of the lateral condyle.

After the condyles themselves have been assembled and fixed together, the supracondylar portion of the fracture is brought into reduction. Oblique threaded pins placed as illustrated in FIGURE 15, the distal tips perforating the cortices of the humeral shaft, will stabilize the fragments unless comminution is too severe. At times, two bone plates or a Y plate and screws will be necessary to provide adequate stabilization of the fragments.

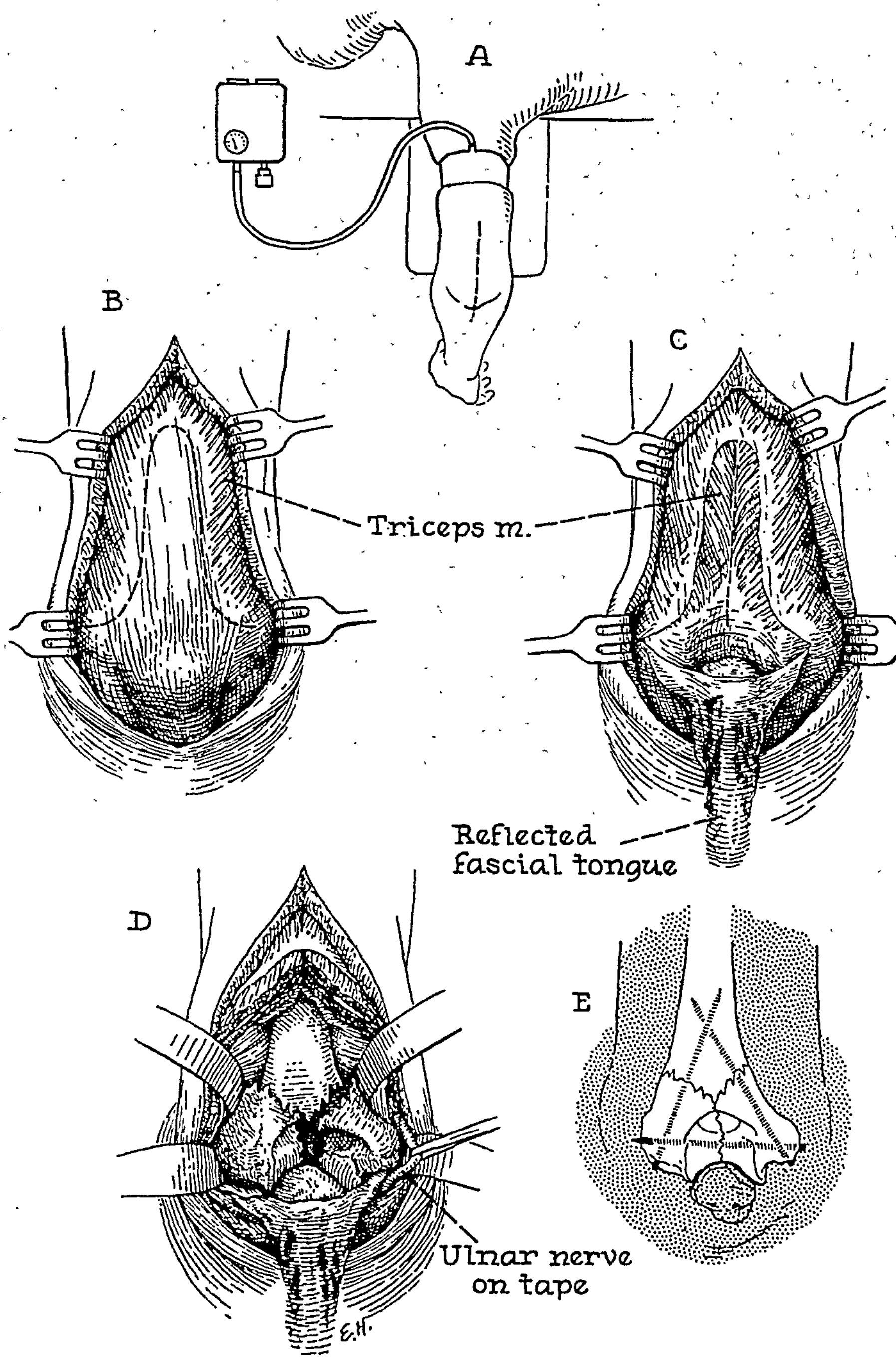


FIG. 14—*Technic of Open Reduction of Supracondylar T-Fracture of Humerus.* (A) The operative position and the line of the skin incision. (B) With the skin and subcutaneous tissue reflected, the fascia over the triceps muscle is incised so as to create a tongue attached at its base toward the elbow. (C) The tongue is reflected and then the triceps muscle and periosteum are incised longitudinally in the midline. (D) The muscle and periosteum are reflected, together with the capsule of the joint, exposing the fracture. The ulnar nerve is dissected from its bed and protected from injury. (E) The fragments are brought into apposition and stabilized by internal fixation (see text).

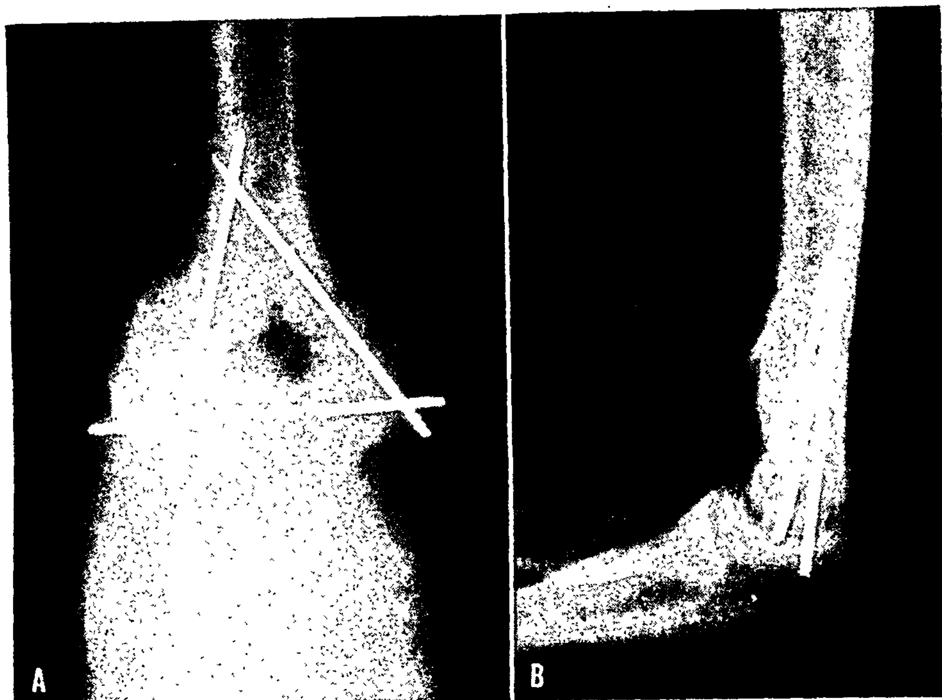


FIG. 15—*Supracondylar T-Fracture of the Humerus.* (A) and (B) Anterior-posterior and lateral views showing a mildly comminuted T-fracture of the distal end of the humerus after open reduction and internal fixation with threaded pins through a posterior incision (see FIG. 14).

After thorough irrigation of the wound, the ulnar nerve is replaced in its groove and the wound is closed, the long tongue of triceps fascia being sutured in position.

A long arm plaster cast holding the elbow at 90 degrees provides the postoperative immobilization. The duration of postoperative immobilization will depend on the quality of fixation of the fragments which was achieved. In some instances immobilization can be discontinued at four weeks but in others it must be maintained for eight weeks and at times longer.

In supracondylar fractures without the vertical split between the condyles, open reduction and internal fixation may at times be achieved through two incisions, one over the lateral condyle and the other over the medial condyle. Exposure is restricted but if the fracture line is brought into good reduction as seen through each of the incisions, oblique pins passed through each condyle into the shaft and through the opposite cortex may be inserted for stabilization of the fragments. Actually, the posterior approach described for T-fractures is preferable even though more extensive dissection

of soft parts is required. The additional exposure and the relative ease of providing a stable internal fixation justify the use of the posterior approach in most supracondylar fractures.

Pitfalls and Precautions

1. Gain adequate exposure before attempting to reduce the fragments.
2. Safeguard the ulnar nerve at all times.
3. Stabilize the condyles into a single unit before attempting to reduce and stabilize the supracondylar fracture.
4. Use adequate internal fixation to hold all fragments reduced. Particularly do not fail to stabilize the condyles to the shaft securely.

Fractures of the Lateral Condyle; Medial Condyle: Fractures of the lateral and medial condyles of the humerus in adults are relatively uncommon. When either is encountered, the principle of precise reduction to restore the congruity of the articular surface of the lower end of the humerus is paramount. If efforts at closed reduction do not provide a "Cabinet Maker's" reduction, then open reduction and internal fixation is indicated.

Adequate exposure is usually obtained by making an incision over the fractured condyle and opening the elbow joint. The fragment is reduced accurately under direct vision and stabilized by a transfixion pin or screw. This technic is described under fractures of the elbow in children (p. 68).

Fractures of the Capitellum: Fractures of the capitellum, a unique group peculiar to the elbow, may be easily overlooked especially if they are associated with an obvious fracture of the head of the radius. The fracture line passes vertically so as to separate the projecting capitellum from the remainder of the lateral condyle of the humerus. The fragment if displaced usually is found in a superior position. Closed efforts at forcing it back into the necessary perfect reduction may be successful but unless excellent reposition is achieved, open operation is indicated. If the fragment is quite small, it may be removed. This permits early active exercises just as soon as wound healing is in progress. Fragments of significant size must be replaced in position and fixed by internal fixation.

Technic: The elbow joint is opened through a lateral incision. Structures attached to the lateral condyle of the humerus are reflected subperiosteally in both anterior and posterior direction. The elbow joint is cleansed of old blood and the fragment is located and its size evaluated. The open reduction of a fragment of significant

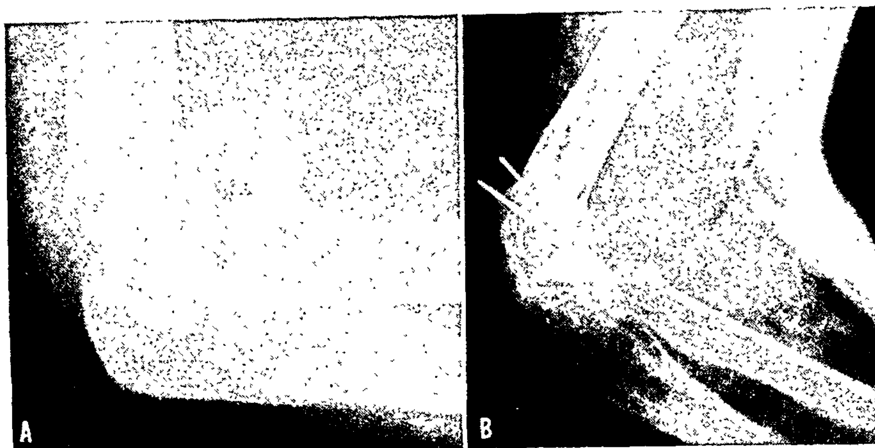


FIG. 16—*Fracture of Capitellum of the Humerus.* (A) Lateral view showing large fragment of capitellum rotated and displaced proximally. (B) Lateral view after open reduction and internal fixation with two unthreaded pins inserted from the posterior aspect of the lateral condyle. The pins were cut off just beneath the skin. They were easily removed after four weeks under local anesthesia.

size is usually not difficult. With the fragment held in excellent reduction, two small threaded or unthreaded pins are drilled from the posterior surface of the lateral condyle across the fracture site well into the fragment (FIG. 16). Check roentgenograms on the operating table are advisable to verify not only the reduction of the capitellum but the position of the transfixion pins. The latter are then cut off flush with the posterior surface of the lateral condyle of the humerus to remain permanently imbedded. The joint and wound are irrigated and the latter is closed in layers. Immobilization is provided for about three weeks by a long arm plaster cast holding the elbow at about 90 degrees.

Pitfalls and Precautions

1. Remove a small fragment of capitellum rather than attempt to stabilize it.
2. Make certain reduction of the fragment is perfect before the internal fixation is inserted.

Fractures of the Head and the Neck of the Radius: Fractures of the neck and the head of the radius in adults even though apparently trivial can result in considerable disability. The head of the radius articulates both with the capitellum of the humerus (within the elbow joint) and with the proximal portion of the ulna at a groove along its radial surface. Malunion of fractures of the head of the radius or excess callus of fractures healed in good position can thus cause limitation of pronation and supination of

the forearm as well as limitation of flexion and extension of the elbow. Fractures of the head of the radius, especially those associated with posterior dislocation of the elbow, also may be complicated by ossifying hematoma.

Fractures of the head and neck of the radius (FIG. 17) either require practically no treatment, the "no immobilization" method, or depending on the size, location and displacement of the fragment, they require open operation. For fissure or crack fractures of the head, for impacted fractures of the neck with little or no dis-

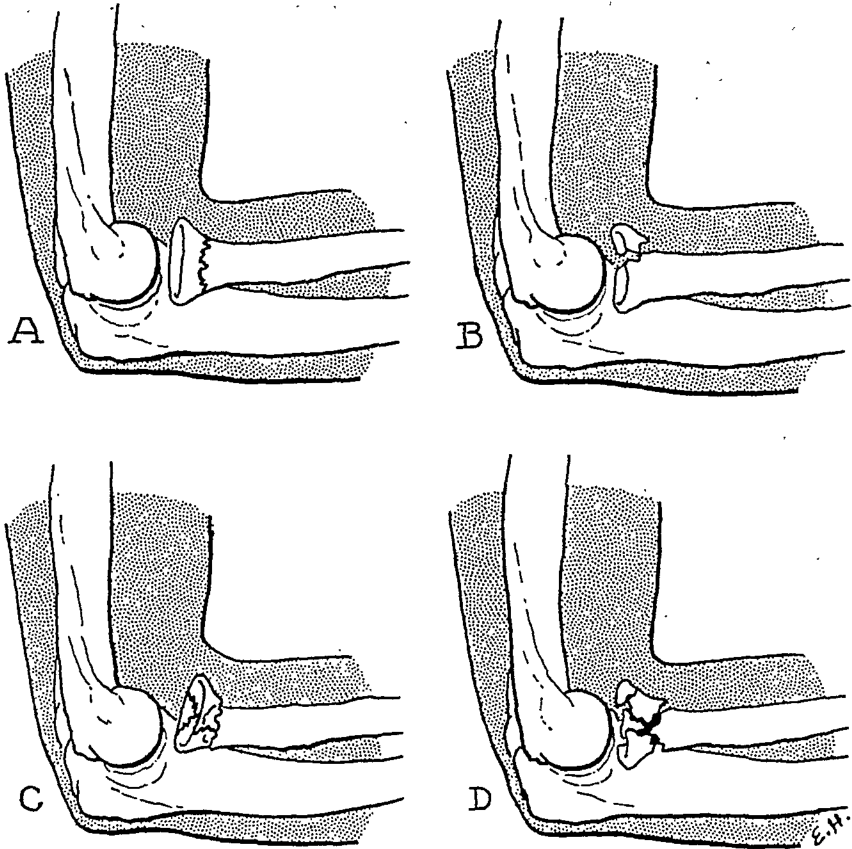


FIG. 17—*Types of Fractures of the Head of the Radius.* (A) Undisplaced fracture which should be treated by early active motion of the elbow (perhaps supplemented by aspiration of the elbow joint). (B) A small displaced marginal fracture of less than one-third of the articular surface for which early operation is indicated. Since this line of fracture is away from the radio-ulnar articulation, excision of merely the the small fragment is acceptable. (C) A comminuted radial head with minimal displacement. Excision of the radial head is indicated. The degree of distortion usually exceeds that shown on x-ray examination. (D) Severely comminuted fracture with gross displacement of the fragments. Excision of all of the fragments is indicated.

placement or angulation and for small marginal fractures of the lateral surface displaced away from the joint, the "no immobilization" method is indicated. A sling, compression dressing and sedation will afford symptomatic relief. Aspiration of the hematoma from the joint decreases pain and allows better motion. Early active motion of the elbow and the forearm is encouraged and may be aided by hot wet compresses to the elbow.

For fractures with significant displacement, open operation with excision of the fragment or the entire radial head is indicated. Fractures requiring an operation include comminuted fractures involving the articular surface of the head of the radius, marginal fractures of the head with displacement toward the elbow joint or merely toward the radio-ulnar articulation, large displaced fractures of the head including more than one-third of the articular surface and fractures of the neck with significant angulation. In doubtful cases with marginal indications for open operation, probably the best interests of the patient will be served by operation, because the extent of damage to the radial head often far exceeds that visualized on roentgenograms. The residual disability following excision of the radial head is insignificant compared to that attendant to leaving a distorted radial head in place.

The operation should be performed as soon as practicable, preferably within one or two days of injury before organization of the hematoma about the fracture site and so active motion of the extremity can be initiated as soon as possible. As a rule, the entire head should be removed and the stump of the neck made as smooth as possible. Occasionally, usually in marginal fractures involving the portion of the head of the radius away from its articulation with the ulna, only the broken and displaced fragment may be removed. Even in these, many authors including Watson-Jones advise removal of the entire head.

Technic: Adequate exposure of the head and neck of the radius may be obtained by a posterior-lateral incision beginning over the lateral condyle a short distance above the radiohumeral articulation and passing obliquely to a point on the ulna about 1½ to 2 inches below the tip of the olecranon. The incision is deepened to expose the plane between the anconeus and the extensor carpi ulnaris muscles. The interval between them is more easily identified in the distal portion of the incision as the muscle fibers are blended near

the origin. These muscles are separated and retracted which brings into view the capsule of the elbow joint overlying the head of the radius. In the upper portion of the incision, fibers of the supinator muscle may be seen beneath the extensor carpi ulnaris. These may be retracted distally. The capsule is opened to expose the pathology.

An alternative method of exposure is through a lateral incision beginning over the lateral condyle and passing down between the fibers of the extensor digitorum communis and the extensor carpi radialis longus muscles. As this incision is deepened the forearm should be kept in full pronation in order to carry the deep branch of the radial nerve as far from the operative field as possible. With separation of the fibers of these muscles for about 1½ inches, the capsule overlying the radial head is brought into view and opened to expose the fracture site. This incision carries some risk of injury to the deep branch of the radial nerve in contrast with the postero-lateral approach described above although with reasonable care and precaution, injury to the nerve always may be avoided.

The fragment or fragments of the radial head are removed. Any periosteal attachments are severed by sharp dissection so as not to further tear the periosteum. Actually it is wise to cut the periosteum in a circular fashion by sharp dissection with a knife at the point to which the stump of the shaft will be trimmed. Enough bone should be cut away to leave a gap of about ½ to ⅝ inch between the stump of the shaft and the capitellum of the humerus.

Many authors advise leaving the periosteum long and closing it by a purse-string suture over the stump of the shaft on the theoretic basis that this tends to minimize callus formation about the raw bone. This not only seems unnecessary but actually undesirable. With the periosteum trimmed flush with the stump of the shaft and this region bathed in synovial fluid, bony proliferation does not occur.

After the head of the radius has been excised, all old hematoma is removed and the entire wound is thoroughly irrigated. Removal of the original hematoma is an important precaution against the complication of ossifying hematoma.

The wound is closed in layers and a compression dressing and sling are applied about the elbow with this joint flexed to about 90 degrees. Just as soon as the reaction about the elbow to the operative procedure has subsided and the wound is healing, active exercises of pronation and supination of the forearm and of flexion and

extension at the elbow are instituted. The latter should be carried out principally toward flexion as extension is regained more easily.

Pitfalls and Precautions

1. Safeguard the deep branch of the radial nerve.
2. Remove fragments by sharp dissection. Avoid tearing of periosteum.
3. Leave as smooth a stump of radius as possible.
4. Irrigate the joint and wound thoroughly to remove as much hematoma as possible.
5. Minimize postoperative immobilization and initiate early motion in the elbow.

Fractures of the Olecranon: Fractures of the olecranon with separation deserve open reduction and internal fixation unless specific local conditions contraindicate it or the general condition of the patient makes open operation unwise. Frequently, by extension of the elbow, separated fragments of olecranon can be approximated and then held by a long arm plaster cast until bony union occurs. Such nonoperative treatment, however, is likely to give an inferior end-result. The fragments although approximated are unlikely to assume a jigsaw puzzle reduction and, therefore, after union the articular surface of the semilunar notch will present some offset or irregularity. Of perhaps greater importance, the hanging position of the extremity with the elbow extended promotes edema of the hand which may lead to permanent stiffness of the fingers. Five or six weeks of immobilization of the elbow in extension, which would be required for union of the fragments, certainly may lead to permanent restriction of motion in that joint.

On the other hand, open reduction and internal fixation permits accurate approximation of the fragments so that the smooth articular surface is restored. External immobilization may be omitted except for a pressure dressing and a sling holding the elbow at a right angle for a few days. Active motion may be initiated as soon as the wound is healed and the use of the extremity may be gradually increased while the fracture is uniting. Closed separated fractures of the olecranon, therefore, are classical indications for primary open reduction and internal fixation.

In open fractures of the olecranon with separation, open reduction and internal fixation are again practically always indicated. Even in those seen several days after injury, accurate approximation of the fragments closes off the elbow joint and minimizes the chances of suppurative arthritis.

Technic: Adequate exposure is obtained through a longitudinal incision over the back of the elbow. A transverse incision perhaps curved a bit superiorly at each end provides somewhat poorer exposure but heals with a less obvious scar because it conforms better to the skin lines. It often may be selected in women. The incision of choice is deepened to expose the fracture site. Blood clot is cleaned out. The elbow joint and fracture site are irrigated with saline.

The method of fixation of the fragments varies with the extent of comminution of the proximal fragment. In transverse fractures, fixation is easy but in those broken into several pieces, it is more difficult.

The fragments may be held in accurate and effective approximation by a long large wood screw, a rigid intramedullary pin or a loop of strong stainless steel wire (FIG. 18A AND B). Occasionally with the screw or pin, a supplemental loop of wire passing through the posterior cortex of each fragment aids in maintaining accurate reduction of the fragments (FIG. 18C–E). The Leinbach olecranon screw, a 5 to 6 inch tapered screw with a smooth proximal third, is highly effective (FIG. 19). With each form of internal fixation, stability should be tested by flexing the forearm to an angle less than 90 degrees before the operative incision is closed.

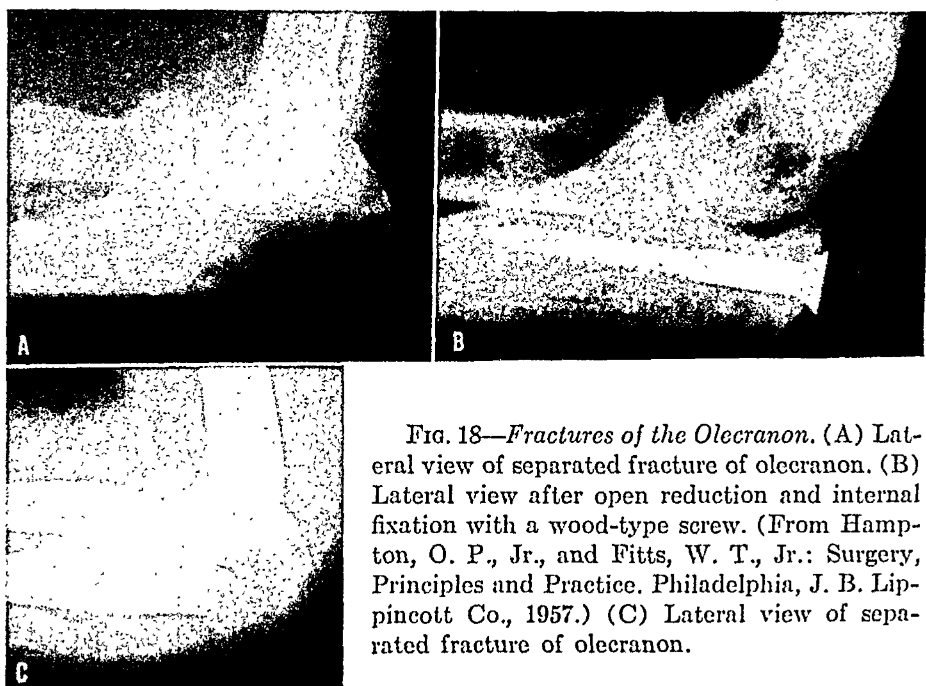


FIG. 18—*Fractures of the Olecranon.* (A) Lateral view of separated fracture of olecranon. (B) Lateral view after open reduction and internal fixation with a wood-type screw. (From Hampton, O. P., Jr., and Fitts, W. T., Jr.: Surgery, Principles and Practice. Philadelphia, J. B. Lippincott Co., 1957.) (C) Lateral view of separated fracture of olecranon.

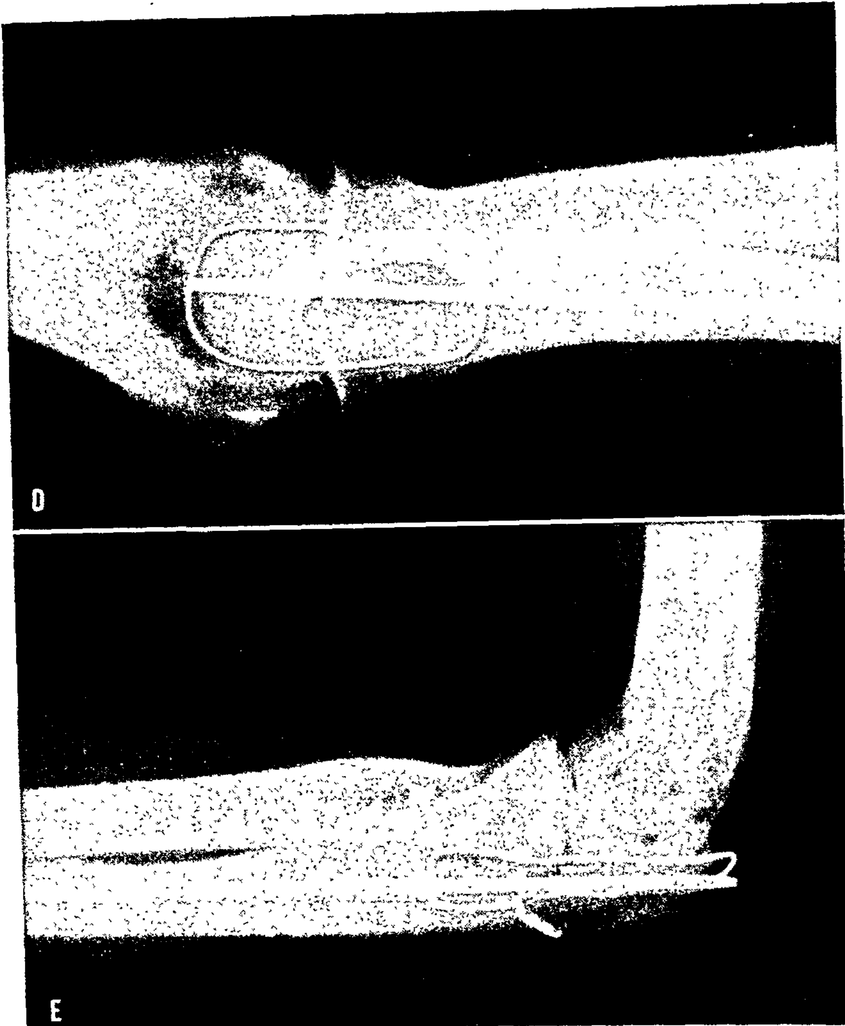


FIG. 18—(D) and (E) Anterior-posterior and lateral views after open reduction and internal fixation with a loop of malleable wire passing through a drill hole in the shaft and beneath the triceps tendon. An intramedullary wire was also used to overcome a tendency toward offset at the fracture line. Usually the intramedullary wire is unnecessary.

When the proximal portion of the olecranon is severely comminuted, the fragments of bone may be excised and the triceps tendon then sutured to the periosteum and triceps expansion over the proximal ulna. This avoids an irregular semilunar notch and minimizes healing time.

Following wound closure, a pressure dressing is applied about the elbow. Elastic bandages are then applied from the hand to the middle third of the arm. A sling to support the forearm at a right angle provides all the immobilization which is necessary.

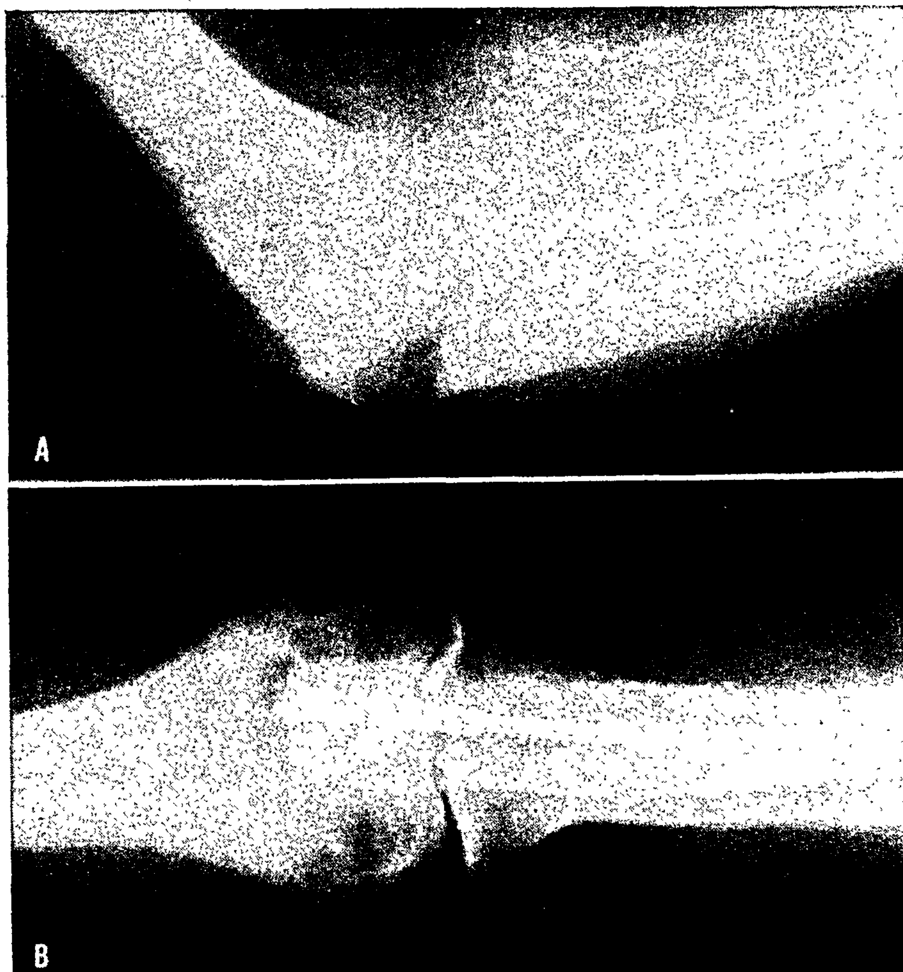


FIG. 19—*Fractures of the Olecranon.* (A) Lateral view of elbow showing separated fracture of the olecranon. (B) and (C) Anterior-posterior and lateral views made in the operating room after open reduction and internal fixation with a Leinbach screw. Note that the flexibility of the screw permits it to follow the curve of the canal of the ulna. (D) Lateral view after union of the fracture.

After the wound is healed, active motion is initiated and increased in both directions as rapidly as is practicable. The fracture should be united in six to eight weeks. A screw or loop of wire does not require removal. Usually, an intramedullary pin is removed under local anesthesia after the fracture has healed.

Pitfalls and Precautions

1. Thoroughly clean the elbow joint of chips and hematoma.
2. Make certain that the reduction of the fragments restores a smooth articular surface.

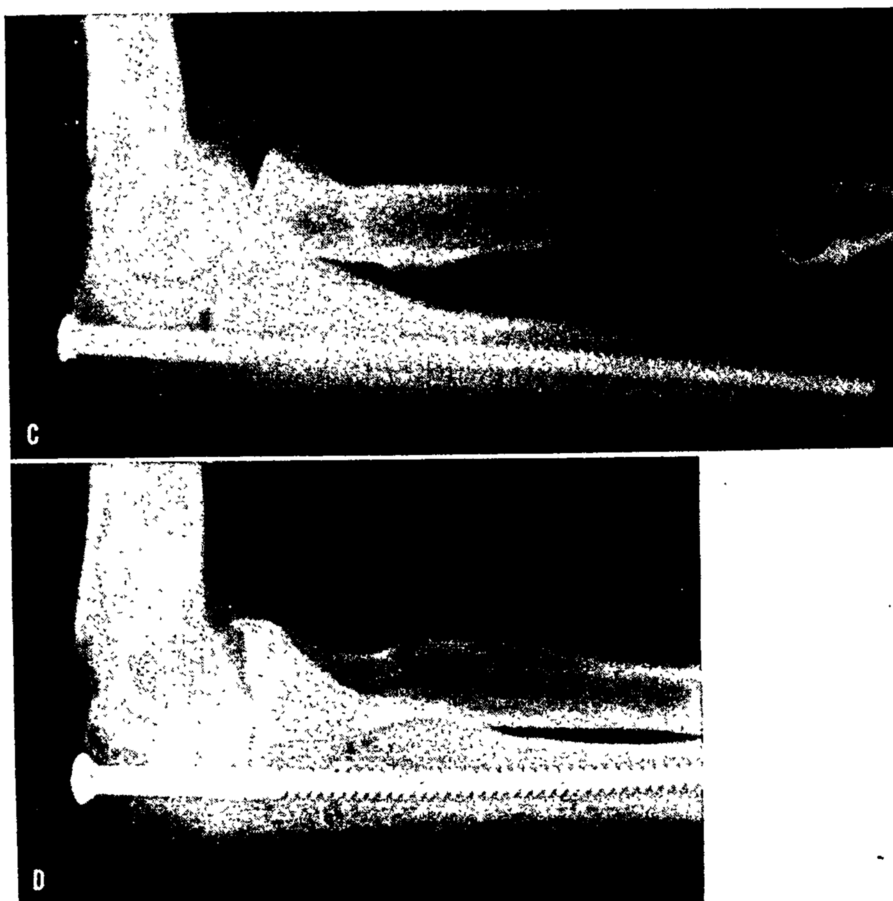


FIG. 19—(C) and (D) *See legend, facing page.*

3. Select the internal fixation to fit the problem. Stabilize the fragments so well that early active motion of the elbow in both flexion and extension may be initiated soon after operation.

Fractures About the Elbow in Children

Common fractures about the elbow in children which may require open reduction and internal fixation are fractures of the lateral condyle of the humerus, fractures of the medial epicondyle of the humerus and fracture-epiphyseal separations of the head of the radius. Open operation is rarely indicated in other fractures of this region in children. Displaced fractures of the medial condyle of the humerus may require operation but this injury is not common. Indications for open reduction of supracondylar fractures in children are almost nonexistent and therefore these injuries do not warrant discussion here, although Speed and Knight state that the Campbell Clinic records show open reduction in 10 per cent of those injuries.

Lateral Condyle of the Humerus: In a fracture of the lateral condyle of the humerus in a child, the fragment includes the epiphysis of the capitellum. The fracture line begins just above the epiphyseal line in the lateral cortex of the lower end of the humerus and extends obliquely downward medially to include a portion of the trochlea. Because a great deal of the fragment may be cartilage, it is easy to underestimate its size.

Fractures of the lateral condyle of the humerus in children must be accurately reduced if disturbances of growths are to be avoided. Fractures without significant displacement require only a few weeks of immobilization. When the fragment is moderately displaced, an effort at closed reduction under anesthesia is justified. If accurate reduction is not obtained or cannot be maintained, then open reduction is indicated. When the displacement is marked, and the fragment may be rotated as much as 180 degrees, open reduction as the primary treatment is justified. In doubtful situations, unless there are specific contraindications, open reduction should be carried out rather than to risk the consequences of inadequate reduction or late loss of reduction in these injuries.

Technic: Adequate exposure is easily obtained through a lateral incision which begins 1½ to 2 inches above the elbow joint and extends downward along the lateral supracondylar ridge to a point about 1 inch below the radiohumeral articulation. The dissection is deepened and the periosteum along the supracondylar ridge is incised and reflected anteriorly and posteriorly. This suffices for visualization of the raw surface of the fracture on the proximal side. A small amount of additional dissection brings the margin of the displaced fragment into view. After cleansing the fracture site of old clotted blood, the fragment is rotated into accurate reduction. Two obliquely placed sharp pins (Kirschner wires to be cut off) are used to stabilize the fragment in reduction (FIG. 20). The torn periosteum of each fragment is sutured for additional fixation but suture alone is really not enough fixation to maintain accurate reduction of the fragment. The pins should be cut off so that a small portion projects from the bone to facilitate removal later. The pins usually are removed after three weeks. Actually they may be allowed to protrude through the skin to facilitate removal at the proper time but the chances of infection are less if they are cut off beneath the skin even though this requires a small incision under local anesthesia for removal. After routine closure of the operative



FIG. 20—*Fracture of the Lateral Condyle of the Humerus in a Child Treated by Open Reduction and Internal Fixation.* (A) Anterior-posterior and lateral views of fractured lateral condyle of humerus with typical rotation of the loose fragment by the common origin of the extensor muscles of the wrist and hand. (B) Anterior-posterior and lateral views after open reduction and internal fixation with one wire nail. The nail was removed several weeks later. (C) Anterior posterior and lateral views made four years later showing union of the fracture in excellent position without growth disturbance. (From Speed, J. S., and Smith, H.: Campbell's Operative Orthopedics, ed. 2. St. Louis, C. V. Mosby Co., 1949.)

incision, immobilization is provided by a plaster cast extending from well above the elbow to the proximal transverse palmar crease of the hand and holding the elbow at 90 degrees and the forearm in midpronation.

Pitfalls and Precautions

1. The fragment of external condyle is always larger than it appears on roentgenograms.
2. If indication for operation seems in doubt, it probably is indicated.
3. At operation, make certain the internal fixation is adequate to avoid redisplacement. Suture of periosteum is usually inadequate fixation.

Medial Epicondyle of the Humerus: Fractures of the medial epicondyle of the humerus are much more common than fractures of the entire condyle itself. They may occur at any time before the epiphysis of the medial epicondyle closes at about the age of 17. This injury which often complicates dislocation of the elbow joint is produced by a valgus strain at the elbow. The epiphysis of the medial epicondyle (really an apophysis since the medial epicondyle does not take part in longitudinal growth) is avulsed away by the common tendon of origin of the flexor muscles of the forearm which arise in part from the medial epicondyle. When the tear is severe, this muscle group tends to pull the medial epicondyle downward and at times it enters the cavity of the elbow joint (FIG. 21). The ulnar nerve may also be traumatized particularly when the medial epicondyle is greatly displaced.

If the fragment of the medial epicondyle shows little or no displacement, only immobilization of the elbow in moderately acute flexion is necessary. If the displacement is as much as 1 cm., open reduction and internal fixation is indicated. When the fragment is displaced into the elbow joint, open operation is mandatory. A careful repair of the torn tendon of origin of the flexor muscles of the forearm is an important part of the operative procedure.

Technic: The fragment of the medial epicondyle, the tear in the fascial origin of the flexor muscles of the forearm and the raw surface on the lower portion of the humerus are usually visualized through a short medial incision. The ulnar nerve is protected from injury. It is identified but preferably allowed to remain in its bed without exposure. The fracture site and elbow joint are cleaned of old blood clots by thorough irrigation. The fragment is replaced and stabilized with an obliquely placed Kirschner wire of adequate diameter to be cut off later. The torn fascial origin of the forearm muscle is repaired with interrupted silk sutures. The Kirschner wire may be cut off flush with the epicondyle and therefore allowed to remain permanently or it may be cut off so as to leave a short projecting portion to facilitate removal at a later date.

Pitfalls and Precautions

1. Avoid injury to the ulnar nerve.
2. Repair rupture of tendinous origin of forearm flexors after medial epicondyle has been stabilized in reduction.

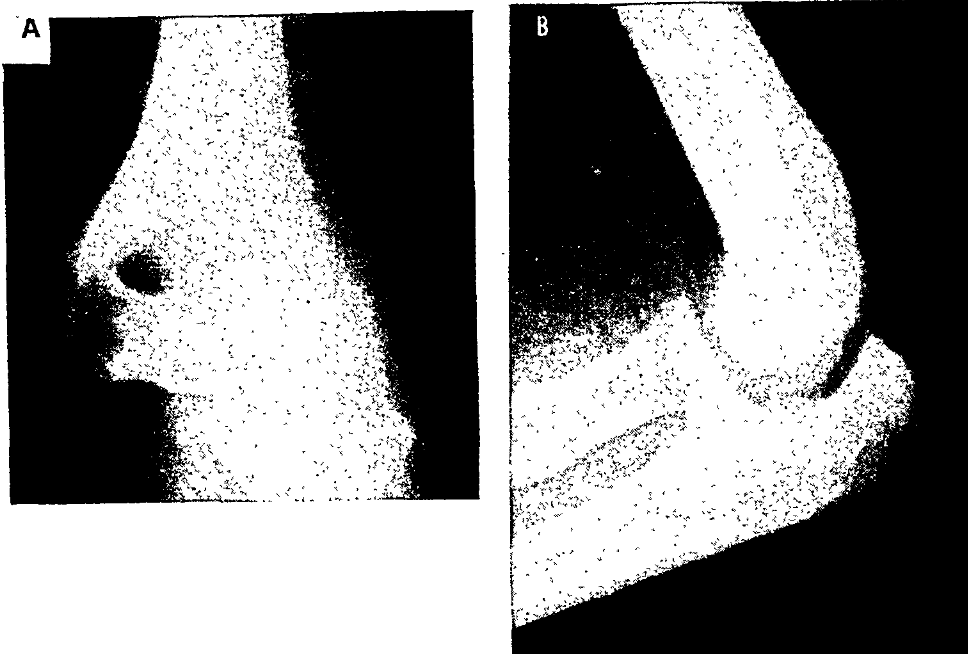


Fig. 21—*Fracture of Medial Epicondyle of the Humerus Complicating a Dislocation of the Elbow.* (A) Anterior-posterior view showing dislocation of elbow and the displaced fragment of medial epicondyle. Note the flat appearance of the medial condyle of the humerus and the epicondylar fragment displaced into the elbow joint. (B) Lateral view after reduction of the dislocation. Note that the medial epicondyle remains displaced into the elbow joint, a situation demanding open reduction.

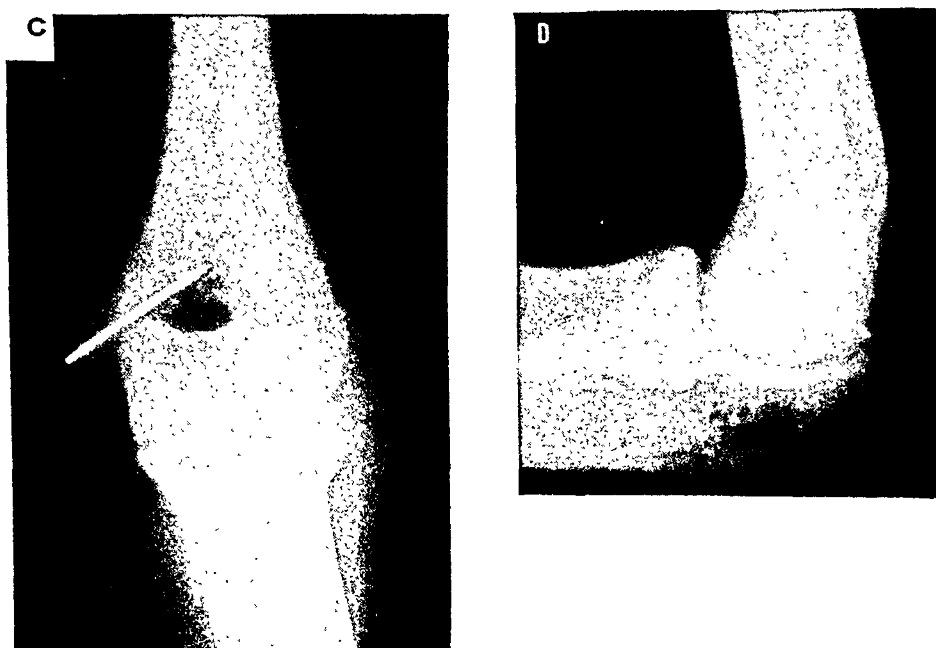


Fig. 21—(C) and (D) Anterior-posterior and lateral views after union of the medial epicondyle which was reduced at open operation and held by a small pin. The latter was cut short flush with the bone and allowed to remain in place permanently.

Head and Neck of the Radius: In children, fractures of the head and neck of the radius are usually fracture-epiphyseal separations. As a rule, the proximal fragment contains the epiphysis, the epiphyseal plate and a triangular portion of the adjacent cortex of the shaft. Comminuted or longitudinal fractures of the epiphyseal head of the radius are quite rare.

Many of these injuries are undisplaced. In others, mild, moderate or severe angulation occurs. A small degree of angulation may be accepted and the injury treated as an undisplaced fracture but if the angulation is severe, it must be corrected. Growth processes are not capable of this correction. Occasionally, under anesthesia a closed reduction may be achieved but more often an open operation must be performed.

In children in contrast to adults the operative procedure is not excision of the radial head, which would lead to permanent shortening of the radius due to loss of growth at the proximal epiphysis, but a true open reduction with correction of the angulation and realignment of the fragments. Even though the proximal fragment might appear to be devoid of blood supply, it must not be removed. Apparently, an adequate blood supply is rapidly re-established.

Technic: The head and neck of the radius are easily exposed through a short posterolateral incision which begins over the lateral condyle of the humerus a short distance above the radiohumeral articulation and passes obliquely toward a point on the ulna about 1 to 1½ inches below the tip of the olecranon. The incision is deepened between the anconeus and extensor carpi ulnaris muscles. An alternative approach is a more true lateral incision with the distal portion passing between the extensor carpi radialis longus and the extensor digitorum communis muscles. With either approach the joint capsule is opened over the radial head. Using the gauze protected thumb or an instrument, the angulation is manually corrected. Often the fracture is found to be greenstick in type and the fracture must be completed to permit correction of the deformity.

As a rule, no internal fixation is indicated. Before closure of the wound the most stable position for the fracture is determined by trying varying degrees of pronation and supination of the forearm and of flexion and extension of the elbow. Usually, the position of midpronation-supination of the forearm and flexion of the elbow

to less than 90 degrees will be selected. Rarely, the reduction is unstable in all positions of the forearm and elbow. In these rare instances, a Kirschner wire may be drilled through the lateral condyle of the humerus from its posterior surface so that the wire traverses the proximal fragment of the radius and terminates as an intramedullary pin in the shaft. The wire should be cut off just beneath the skin behind the lateral condyle so that it may be easily located and removed two to two and one-half weeks later.

After thorough irrigation of the wound and closure, a long arm plaster cast is applied holding the elbow and forearm in the desired position. Immobilization is continued for three to four weeks at which time roentgenograms will usually show solid union of the fracture.

Pitfalls and Precautions

1. Do not remove the radial head in a child; replace it.
2. Avoid damage to the epiphyseal plate.
3. Internal fixation is not necessary as a rule.

MONTEGGIA FRACTURES: FRACTURES OF THE SHAFT OF THE ULNA WITH DISLOCATION OF THE HEAD OF THE RADIUS

A Monteggia fracture (FIG. 22), really a fracture-dislocation—a fracture of the shaft of the ulna with dislocation of the head of the radius (usually anterior)—is a complex injury requiring precise management. Not only must the radial head be held reduced but also perfect apposition and alignment of the ulna must be obtained and maintained. If the ulna heals in even slight angulation or minimal overriding, relative shortening of this bone is established and the function of the humeroradial articulation is impaired even though the radial head may or may not redislocate. To insure that the fracture of the ulna is held reduced perfectly, open reduction and internal fixation is necessary.

Usually, the fracture of the ulna is somewhat oblique rather than transverse so that the indication for internal fixation is obvious. It is emphasized, however, that the same quality of internal fixation is needed even though the fracture line is transverse and an excellent closed reduction has been achieved because angulation is very likely to occur in spite of a good plaster cast. Moreover, the orbicular ligament may be torn as the radial head dislocates. An intact orbicular ligament or a torn portion of it may become caught be-

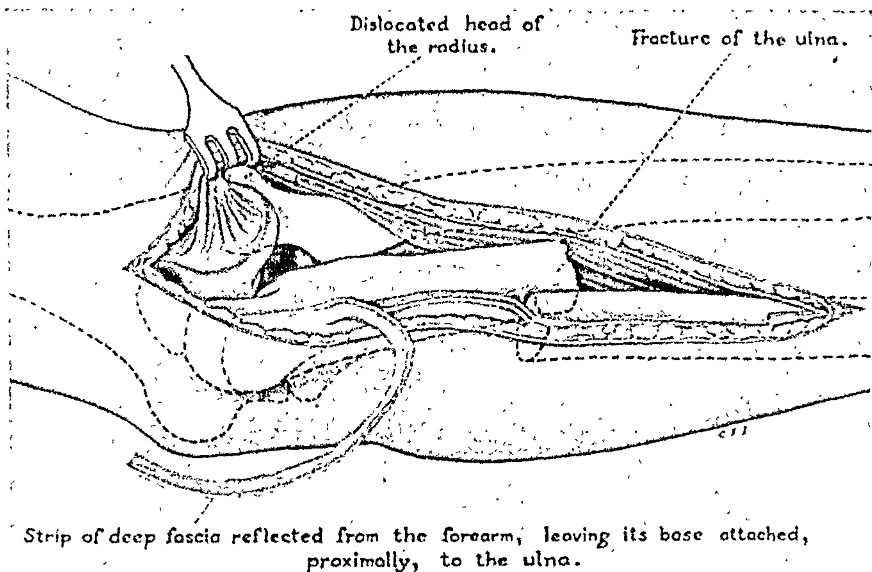


FIG. 23—(B) Exposure of fracture of ulna and dislocation of the radius. The fascial strip is for reconstruction of the orbicular ligament (see text).

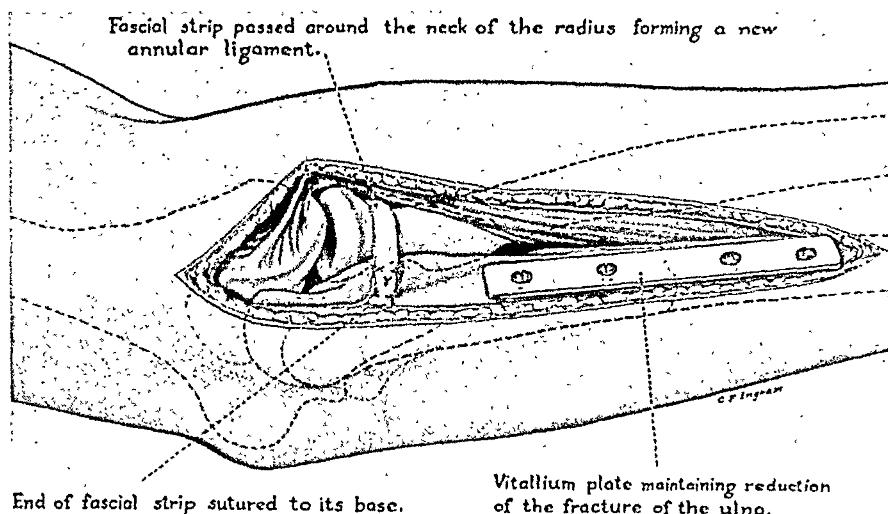


FIG. 23—(C) The completed operation. An intramedullary pin is now considered preferable to a plate for internal fixation of the ulna.

If it is torn, at times it can be repaired, but the ulna is first reduced and stabilized.

Sufficient periosteum is then stripped adjacent to the fracture of the ulna to provide adequate exposure, and the fracture is reduced. Stable internal fixation may be provided by an intramedullary pin

of adequate size to fill the canal of the ulna (FIG. 22; see page 86 for technic of insertion) or by a plate of four or six holes and screws. Loops of stainless steel wire will not suffice. With either acceptable form of fixation, the fragments of ulna must be in firm contact.

After the internal fixation of the ulna has been achieved, the orbicular ligament is repaired or a new ligament is made if either is indicated.

A destroyed orbicular ligament may be reconstructed according to Speed and Boyd. The decision to do so is made prior to internal fixation of the ulna. A strip of fascia of the forearm muscles attached to the upper ulna about ½ inch wide and 4½ inches long is dissected upward (FIG. 23B). The proximal end of the strip remains attached to the periosteum on the dorsum of the olecranon. The free end is passed between the proximal ulna and the radius and then around the radial neck but not sutured at this time. After stabilization of the ulna, the new ligament is drawn snug and sutured to itself (FIG. 23C).

A long arm plaster cast with the elbow at 90 degrees and the forearm in midpronation is necessary until bony union of the ulna has occurred. This requires at least eight weeks and often longer.

Primary Bone-Grafting: Nonunion of fractures of the proximal half of the shaft of the ulna is not uncommon. It may occur even after a technically splendid internal fixation with a plate and screws or an intramedullary pin. Even though union may be obtained subsequently after bone-grafting, the eventual functional result will be impaired further and delayed.

For these reasons primary bone-grafting of the fracture of the ulna using small strips and chips of iliac bone should be carried out in many instances. The additional surgery is minimal and the advantages are tremendous since not only are the chances of nonunion minimized but the period required for bone-healing is shortened so that immobilization may be discontinued sooner. This in turn predisposes to a better functional result in a shorter period of time.

Pitfalls and Precautions

1. Do not overlook the dislocated head of radius in the presence of the obvious fracture of the ulna.
2. Safeguard the deep branch of the radial nerve.

3. Rigidly stabilize the fracture of ulna in perfect alignment as an aid to perfect reduction of the radial head.
4. Make certain that a torn orbicular ligament is not caught between the radial head and the capitellum.

FRACTURES OF THE SHAFT OF THE RADIUS AND/OR ULNA

Fractures of the shaft of either the radius or ulna or both are best managed by open reduction and internal fixation with but few exceptions. Exceptions are fractures in children at all levels, stable fractures of the proximal portion of the radius or the distal portion of the ulna, and an occasional fracture at other levels which has not been displaced significantly and is so stable that a long arm plaster cast may be applied without any subsequent change in the apposition or alignment of the fragments and with the anticipation that the reduction will be maintained by the cast. The great majority of fractures of the shafts of the bones of the forearm in adults and late adolescents do not fall within these exceptions and deserve the advantages offered by open operation unless this is contraindicated by local conditions of the skin or circulation or the general condition of the patient.

This seemingly radical concept is not radical at all. Speed and Knight have aptly termed these "unsolved fractures." Quoting data collected by Smith and others in their group, they point out that nonoperative methods not only give a relatively high percentage of nonunion but a high degree of malunion and limited function in those which do unite. With open reduction and internal fixation, the optimal return of function may be expected in those which unite. Nonunion is still a problem but even in those which fail to unite, malunion and synostoses are prevented and eventually with bone-grafting followed by union of the fracture, the subsequent functional end-result is far superior to the results obtained too often by closed reduction. The best results come with open reduction and internal fixation supplemented by primary bone-grafting.

Fractures of the radius and ulna present a complex problem for several reasons. These bones bear a distinct interrelationship both at the elbow where the radial head rotates in the orbicular ligament during pronation and supination and at the wrist in the inferior radio-ulnar articulation. They are involved separately in the humero-ulnar and humeroradial articulations at the elbow and the radiocarpal joint at the wrist.

In addition to this interrelationship at the elbow and wrist, the entire radius and ulna have a fixed functional interdependence. For all the movements in the several joints to be carried out efficiently, the normal relationship of the radius and ulna in length and design must be maintained. Any actual or relative shortening or angulation of either bone disturbs function of the forearm. Not only will the range of pronation and supination be limited, but flexion and extension at the elbow or wrist may be impaired. It is essential, therefore, that full length and perfect alignment of both bones be restored in the management of these fractures if the best obtainable result is to follow. These usually can be achieved only by open reduction and internal fixation of the fragments of the broken bone or bones. A snug plaster cast applied after closed reduction with fragments in fine supposition and alignment is unlikely to maintain this good reduction of the fragments as the varying and multiple pulls of forearm muscles are likely to cause angulation and even displacement of fragments within the cast.

Operative Position: The best operative position for fractures of the shaft of the ulna is provided with the pronated forearm across the chest. This position is also excellent for fractures of the shaft of the radius when the dorsal operative approach is to be used. For the volar approach to the radius, the supinated forearm should be placed on an arm board or side table with the elbow extended so that free access to the volar surface of the forearm may be obtained. With careful draping, the forearm may be moved easily from one of these positions to the other. The sterile field must include from the lower portion of the arm (just below the compression tourniquet) above the elbow to at least the proximal transverse palmar crease of the hand.

Technic: Exposure of the fracture site of the ulna is easy as the bone is entirely subcutaneous. An incision of 1 to 2 inches just away from and usually on the dorsal side of the crest will suffice for exposure of the fracture for intramedullary pinning but one of at least 4 inches is necessary for plating.

Exposure of the fracture site of shaft of the radius is not as simple at any level. Either a volar or a dorsal approach may be used but each requires some caution to protect vital structures such as the deep branch of the radial nerve in fractures of the proximal third and the radial artery in those of the distal third.

The anterior or volar approach to the shaft of the radius is made through a skin incision in a line just lateral to the biceps tendon and passing toward the radial styloid while the forearm is in supination (FIG. 24). After the incision has been carried through the fascia, the radial artery at all levels must be identified and protected. In the proximal portion of the forearm as part of the dissection

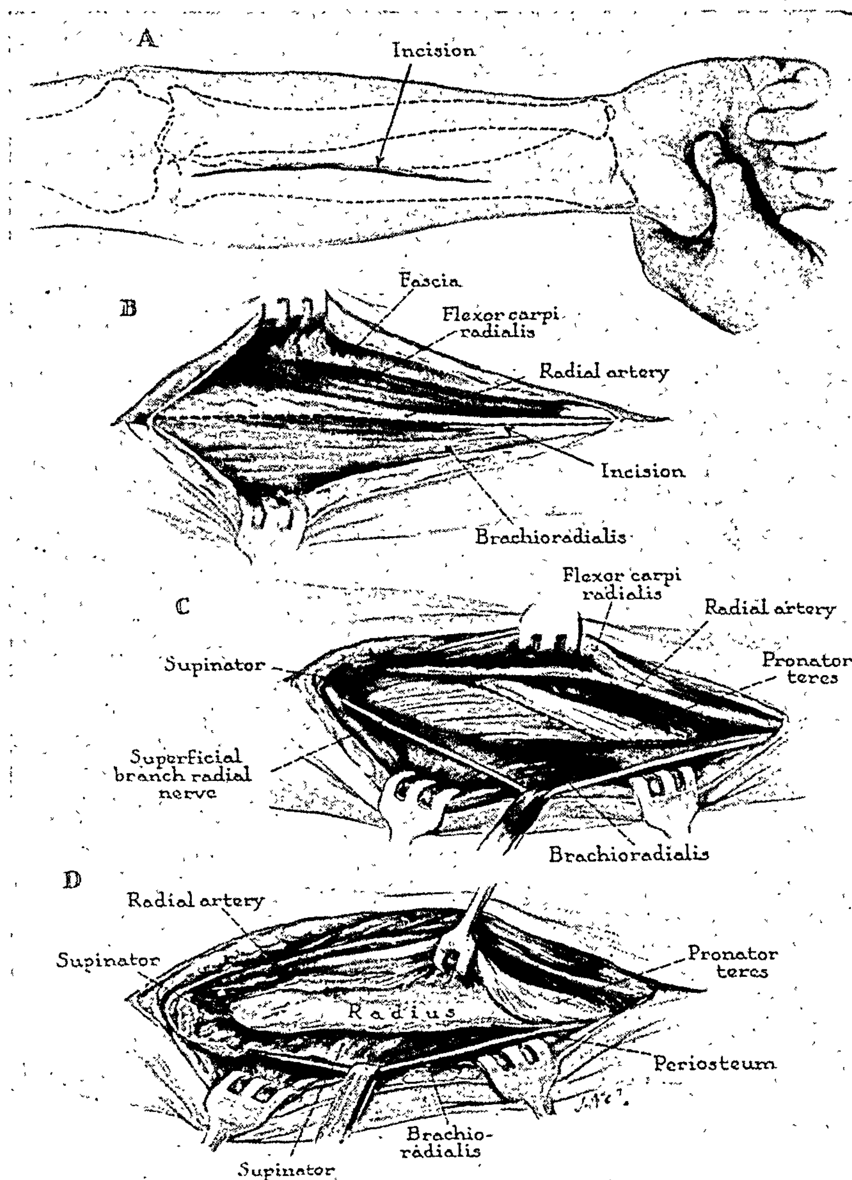


FIG. 24—*Technic of Volar Exposure of Proximal Portion of Shaft of Right Radius.* (From Banks, S., and Laufman, H.: Exposure of the Extremities. Philadelphia, W. B. Saunders Co., 1956.)

necessary to expose the radius, it is advisable to identify, ligate and sever the radial recurrent artery. Then the supinator muscle is easily visualized and its insertion into the radius is incised. As the muscle is retracted laterally, the radial nerve is carried with it and protected. By pronation of the forearm even the dorsal radial surface can be visualized.

In the distal portion of the forearm, the anterior or volar approach (FIG. 25) is somewhat more difficult than the posterior but

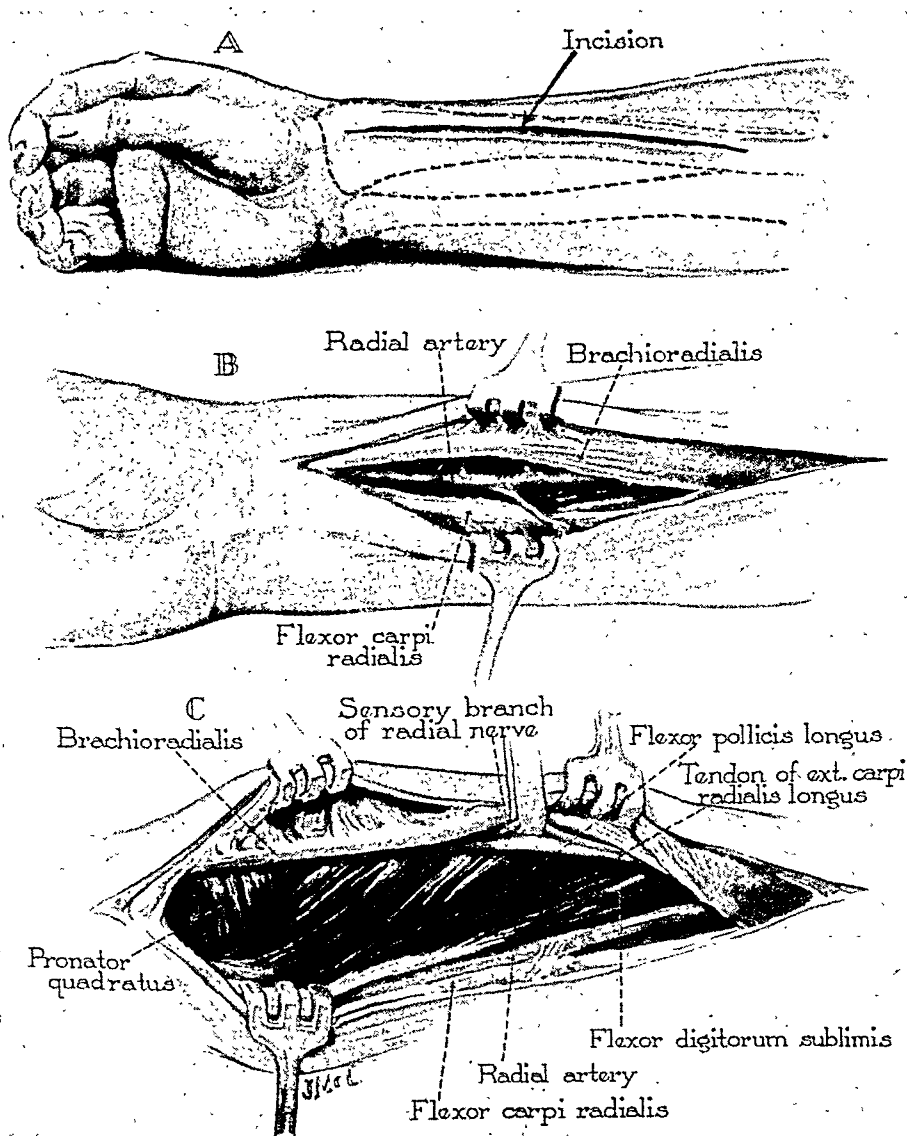


FIG. 25—*Technic of Volar Exposure of Lower Half of Shaft of Right Radius.* (From Banks, S., and Laufman, H.: Exposure of the Extremities. Philadelphia, W. B. Saunders Co., 1956.) (A) Incision and exposure and retraction of radial artery with forearm in supination.

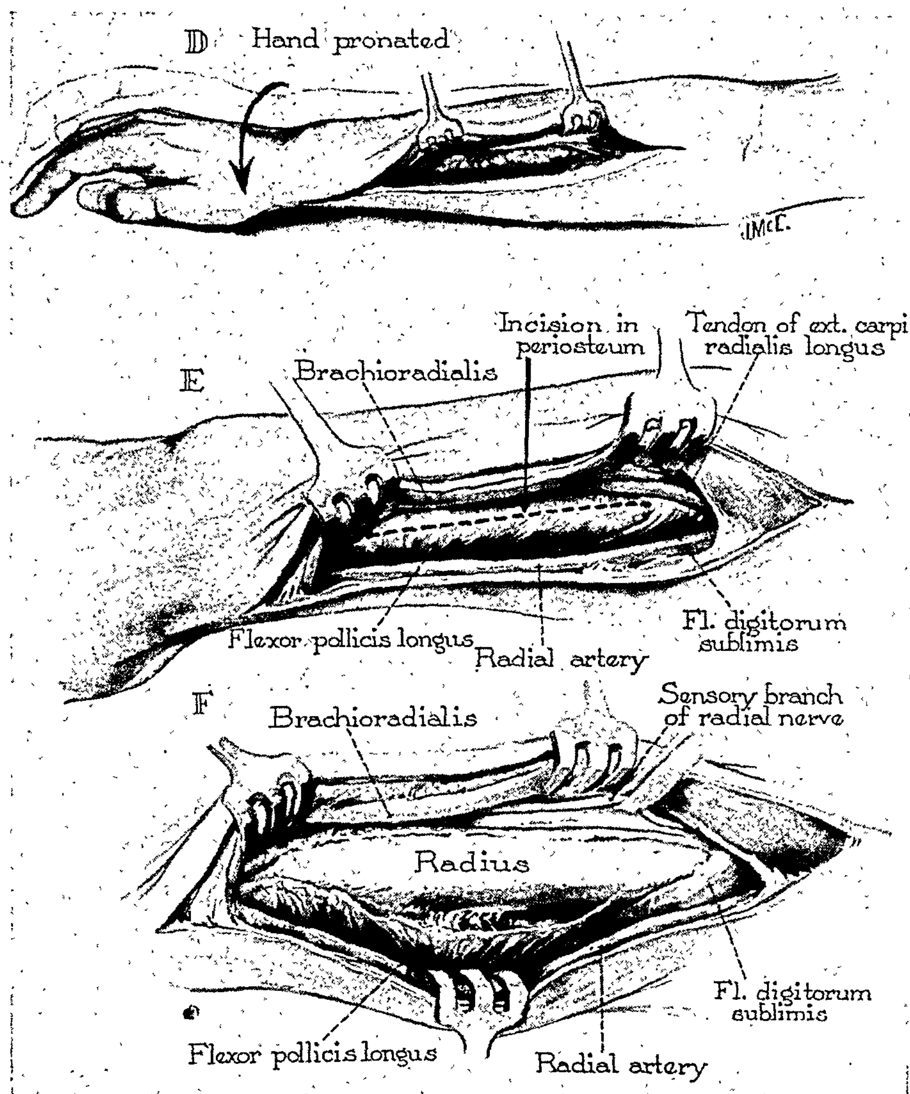


FIG. 25—(B) Exposure of radial shaft after pronation of forearm.

even so, it probably is preferable for several reasons. The resulting scar is less noticeable, the flat anterior surface of the radius permits better contact of a plate and the exposure is complete. With the posterior incision at this level, by contrast, the scar is in a conspicuous location, the dorsal surface of the radius is not flat and the abductor of the thumb interferes, as it is constantly in the operative field and must be retracted first one way and then the other. The incision is carried down to expose the border of the brachioradialis tendon which is retracted laterally. The flexor carpi radialis tendon and the radial artery are retracted medially. The forearm is then

pronated which brings into view the origin of the flexor pollicis longus. The periosteum is incised just lateral to the origin of that muscle and stripped so as to expose the fracture site.

The dorsal approach passes between the common extensor of the fingers and the radial extensors of the wrist. In the proximal half of the forearm, particularly in the upper third, exposure is not easy and maximum care is necessary to avoid injury to the deep branch of the radial nerve (the anterior approach seems preferable). The skin incision is made in a line between the extensor of the fingers and those of the wrist. After the fascia has been incised, the former is retracted medially and the latter laterally to expose the supinator muscle. The insertion of this muscle into the radius may be severed as anteriorly as possible and the periosteum stripped beginning distally and working proximally. The radial nerve is protected as the muscle is retracted medially. As an alternative, the supinator may be incised in the line of the skin incision until the radial nerve is exposed and can be retracted. Then the deep portion of the muscle and periosteum are incised and retracted to gain exposure of the fracture site.

In the distal half of the forearm, the dorsal approach permits easy exposure of the radius but the long abductor of the thumb is usually in the way and must be retracted alternately in each direction. The skin incision, centered over the fracture site, passes directly over the dorsal surface of the radius. After the dorsal fascia has been incised and the overlying portion of the abductor pollicis longus muscle has been isolated, the fracture site is visualized.

Methods of Internal Fixation: Adequate internal fixation of fractures of the shaft of either the radius, ulna or both may be provided in several ways (FIGS. 26–28). These include intramedullary pins of sufficient length and diameter, four hole plates and screws, occasionally two transfixion screws (one is seldom sufficient) in oblique fractures, and, rarely onlay cortical bone grafts. Loops of malleable stainless steel wire do not provide adequate internal fixation for any of these injuries.

When both bones are broken, the internal fixation of the fracture of the ulna should be carried out first. A stable ulna facilitates reduction and internal fixation of the fracture of the radius. Each fracture is approached through a separate incision, never through a single incision.



FIG. 26—*Fracture of Both Bones of Forearm Managed by Open Reduction and Internal Fixation.* (A) and (B) Anterior-posterior and lateral-oblique views showing fracture of shaft of radius in the proximal half and of the ulna in the distal half. Through a volar approach, the fracture of the radius was stabilized with a Rush pin inserted retrograde from the radial styloid; the oblique fracture of the ulna was fixed internally with two screws through a separate incision. (C) and (D) Anterior-posterior and lateral views made soon after operation showing excellent apposition and alignment of both fractures. (E) and (F) The end-result following removal of the pin from the radius after union of the fractures.

Intramedullary Fixation (FIGS. 26 AND 27): Intramedullary pinning offers many advantages as the means of internal fixation for fractures of the bones of the forearm. Because only minimal exposure of the fracture site is necessary, skin incisions may be short, dissection of soft parts is not extensive (danger of injury to major vessels and peripheral nerves of the forearm is reduced) and periosteal stripping is avoided or at the most restricted to the region adjacent to the fracture. Excellent apposition and alignment of the fractures can be achieved. Intramedullary pins of proper diameter allow for continuing contact-compression of the fragments due to normal muscle tone and do not predispose to persisting gaps between the fragments (p. 21).

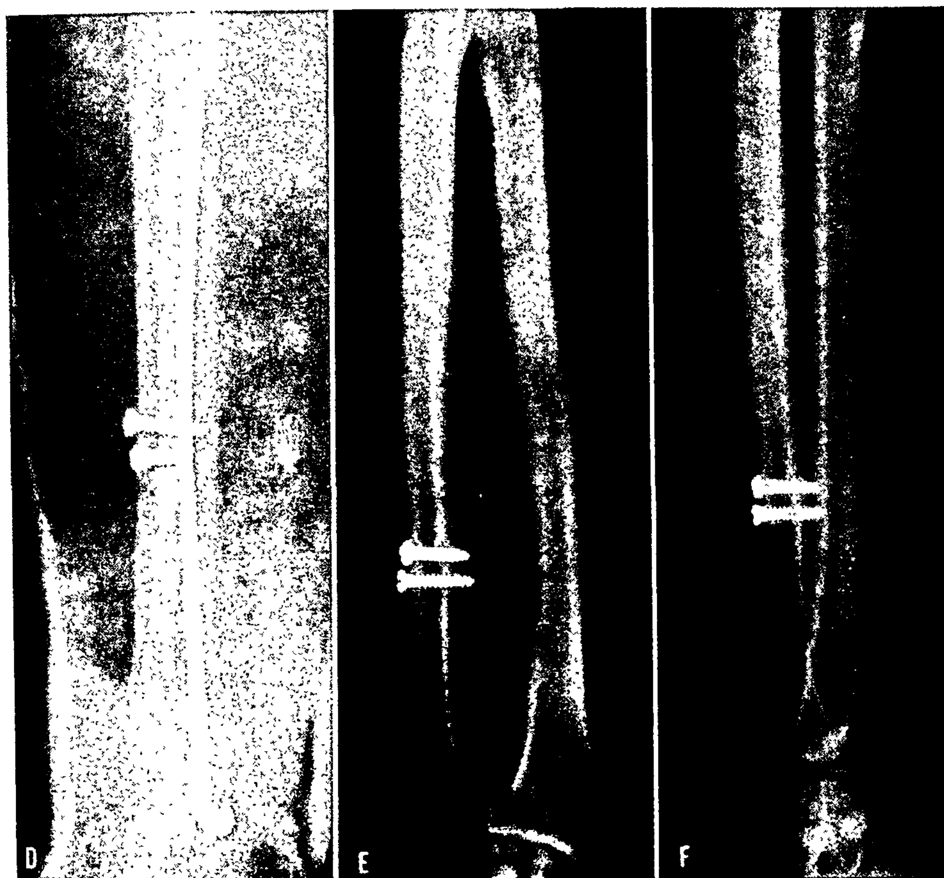


FIG. 26—(D-F) *See legend, facing page.*

Intramedullary pins have certain pitfalls and disadvantages. Failure to use pins of proper diameter can lead to poor results. If the pin is too large, particularly in the ulna, it can distract fragments as it is driven across the fracture site into the distal fragment and, if this is allowed to persist, nonunion is likely to follow. A pin too large can explode either fragment and create a relatively catastrophic situation. If the pin is too small, the fixation is poor and angulation and rotation can occur, particularly in the radius, so that nonunion is favored. In the ulna with a pin of correct diameter, alignment is easily obtained as the canal is straight. In the radius, however, the canal is curved and precise technic is necessary to insert the pin and yet preserve the radial curve. To accept even minimal angulation predisposes to nonunion of the radius. Moreover, if the normal curve of the radius is eliminated by a straight intramedullary pin, the over-all length of the radius is increased. This in turn tends to strut the fragments of ulna apart and pre-



FIG. 27—*Fracture of Shafts of Both Bones of the Forearm Managed by Open Reduction and Internal Fixation with Rush Pins.* (A) and (B) Anterior-posterior and lateral views prior to operation showing fracture of each bone in the midthird.

disposes to nonunion of that fracture. Knight has stated that while the Rush pin is now the best available for the radius, it is not ideal and an improved pin is needed.

Intramedullary Fixation of the Ulna: Intramedullary fixation is achieved with a pin which will fit snugly in the canal of the ulna. The Rush pin or Schneider self-broaching pin appears to be the best



Fig. 27—(C) and (D) Anterior-posterior and lateral views made 8 weeks later at a change of cast. Each fracture line is still visible and the appearance of that of the ulna suggested that nonunion was a possibility. (E) and (F) Both fractures united. Anterior-posterior and lateral views showing an excellent end-result after removal of the Rush pins.

available today. If the canal is rather small, a Kirschner wire or small Steinmann pin may be preferable. The intramedullary pin is inserted downgrade from the olecranon in all fractures of the proximal and middle thirds of the ulna. When this technic is employed for a fracture of the distal third, the pin is inserted retrograde from a point about ½ inch above the styloid.

The forearm is placed across the chest. The fracture site is exposed through a short incision and adequately cleaned of old blood clot. Another short incision is made over the back of the olecranon. Fibers of the triceps tendon are split sufficiently to expose enough

cortex of olecranon to permit a 7/64 inch drill hole to be made toward the canal of the ulna. A pin of sufficient length (1 to 2 inches shorter than the ulna; the more distal the fracture, the longer the pin) is then driven down the canal of the ulna until it presents at the fracture site. Then the fracture is held reduced while the pin is driven home. If the pin binds excessively at any point it must be withdrawn and either the canal enlarged by drilling or a pin of smaller diameter selected. Explosion of either ulnar fragment must be avoided at all costs. Moreover, distraction at the fracture site must not be tolerated. At times this can be overcome by manually forcing the distal fragment back on to the pin until firm contact at the fracture site is achieved.

For intramedullary pinning of fractures of the distal third of the shaft of the ulna, the incision for retrograde insertion of the pin is made over the lateral surface of the ulna and an oblique drill hole is made, slightly larger than the pin to be used. The length of the pin may be several inches shorter than the length of the ulna itself. The pin is inserted until the tip appears at the fracture site after which reduction of the fracture is carried out and the pin is inserted completely.

Intramedullary Fixation of the Radius: Technically, intramedullary pinning of a fracture of the shaft of the radius is much more difficult than that of a fracture of the shaft of the ulna. The canal of the radius is larger than that of the ulna (which actually facilitates passing of the pin) but the only points of fixation for stability are at the cortex at the point of entry and in the cancellous portion of the proximal portion of the radius and, therefore, a stable fixation is not easy to achieve. Of great importance, when the pin has been completely inserted, it should conform to the natural curve or arc of the radius. This also is not easy to achieve.

In the intramedullary pinning of a fracture of the shaft of the radius, the pin is always inserted retrograde from the distal end of the bone. After the fracture site has been exposed and cleansed, the region of the styloid process is exposed through a short incision between the tendons of the extensor carpi radialis longus and the extensor pollicis brevis which places the distal portion of the incision within the anatomic snuffbox. The incision is deepened and the styloid process is exposed. About ½ inch proximal to the tip, a drill hole slightly larger than the pin is made in an oblique direction toward the canal of the radius.

The Rush pin or a modification with a rounded rather than a pointed end is the best available for fractures of the shaft of the radius. A pin of a length about 1 to 1½ inches shorter than the radius is molded into a curve comparable with the normal curve of the radius with the convexity of the pin in the direction opposite to that of its crook. The pin is then inserted with the convexity of the curved pin opposite to that of the normal curve of the radius. The pin is advanced until it presents at the fracture site. The fracture is reduced and then the pin is driven on up the canal of the proximal fragment. Experience shows that the pin will rotate 180 degrees so that when the crook is seated in the drill hole in the styloid of the radius, the curve of the pin will follow the normal arc of the radius. As a rule, distraction at the fracture site is not a problem in the radius. The problem is to avoid angulation.

As a general rule, intramedullary pins are removed after the fractures are united. A well seated pin may remain in the ulna if the back of the elbow is not sensitive. The majority of patients with a Rush pin in the radius have some sensitivity at the styloid of the radius until the pin is removed. Either pin may be removed under local anesthesia.

Plates and Screws (FIG. 28): A plate and screws properly applied provide the most stable internal fixation for fractures of either or both of the bones of the forearm. The method will hold full length and alignment even with some comminution of the fracture. These, however, are about the only advantages offered by a plate and screws.

The method has several disadvantages. Longer incisions, more soft part dissection, and more periosteal stripping and other trauma at the fracture sites are required. These entail more risk to vital structures such as major peripheral nerves. The plate, moreover, often must be placed where available soft parts for coverage are at a minimum. All of the factors predisposing to nonunion with plating (p. 3) accrue in the forearm.

Technic: The same operative position and approaches to the fracture are used as in intramedullary pinning but the latter must be more extensive and fully developed. The technics of plating conform to those outlined in Chapter I (pp. 11–18). A plate should be placed on the side of each bone which will permit the best coverage during wound closure.

Primary Bone-Grafting: Unless there is a valid reason to the con-



FIG. 28—*Fracture of Shafts of Both Bones of the Forearms Fixed Internally by Plates and Screws.* Preoperative and postoperative roentgenograms showing fracture of shafts of both bones of forearm stabilized internally by standard plates and screws. The fractures went on to solid union and the plates caused no symptoms.

trary, primary bone-grafting should be carried out in addition to internal fixation in practically all fractures of the shaft of the ulna and in many of the radius at the junction of the middle and distal thirds. Union comes slow at best in both of these groups and primary bone-grafting will increase the chances of union and minimize the period of healing. Chips and small strips of cancellous bone (usually from the wing of the ilium) are placed in and across the fracture sites in contact with denuded bone. Only a moderate amount of donor bone is necessary.

Postoperative Care: Immobilization in a long-arm plaster cast with the elbow at 90 degrees, the forearm in midpronation and the wrist in slight dorsal flexion is necessary with all forms of internal fixation. The immobilization must be continued until definite evidence of union crossing all fracture sites can be seen on subsequent roentgenograms. Although following adequate internal fixation, external immobilization may be discontinued with less evidence of full union than if only closed reduction without internal fixation had been performed, the ultimate end-result should not be jeopardized by too early removal of the plaster cast.

Pitfalls and Precautions

1. Perfect apposition and alignment and full length of both radius and ulna must be obtained if a good functional result is to follow.
2. Restore the normal arc of the radius if at all possible.
3. Never attempt open reduction of fracture of both bones through one incision.
4. Avoid a gap between fragments.
5. Consider the advantages of primary bone-grafting.

3 *Fractures of the Lower Extremity*

FRACTURES ABOUT THE HIP

FRACTURES ABOUT THE HIP for which operative management is commonly indicated include fractures of (1) the neck of the femur, (2) trochanteric region of the femur and (3) posterior wall of acetabulum associated with a posterior disclocation of the head of the femur.

Fractures of the Neck of the Femur (Intracapsular Fractures of the Hip)

Fractures of the femoral neck with displacement of the fragments carry a high rate of nonunion (15 to 35 per cent in various series). In those which do unite bony union comes slow and even in the latter group avascular necrosis of the femoral head with resulting pain and restricted motion is ultimately to be expected in 25 to 30 per cent. They remain as a group, therefore, "the unsolved fractures."

Internal fixation of the fracture is indicated in the overwhelming majority of patients with fractures of the femoral neck. About the only exceptions are fractures in moribund patients, those in patients who were unable to walk at all prior to the fracture and could not be expected to walk in the future (in these internal fixation may be indicated to relieve pain promptly) and perhaps in those with fractures firmly impacted in valgus position. Actually, we advocate internal fixation in most of the latter group. In selected instances the operative management of displaced fractures may embrace implantation of a hip joint endoprosthesis instead of internal fixation of the fracture.

Technic of Closed Reduction and Internal Fixation: The most crucial part of the operation for internal fixation of a fracture of the neck of the femur is the reduction of the fracture. Without practically perfect (or slight valgus) reduction, the end-result is prejudiced from the start. Closed reduction is highly preferable to open reduction but the latter must be used if efforts at closed reduction do not lead to excellent replacement of the fragments.

Reduction may be achieved by appropriate maneuvers on any one of the modern fracture tables. The patient is placed on the table

in the position which brings the perineum snugly against the perineal post. Impaction in faulty position, if present, is first broken up by forceful internal and external rotation until intra-articular crepitus is obtained, then the feet are bandaged to the foot pieces. Enough traction is applied to the uninjured extremity to make it reasonably taut. The injured extremity is placed in full external rotation and neutral adduction. Sufficient traction is applied to create a tendency for the extremity to swing toward abduction at the hip. This indicates that enough traction has been provided. Then, the thigh is internally rotated to the maximum after which it is brought into moderate abduction and all adjustable screws on the table controlling the extremity are locked in position.

An alternative method of reduction is furnished by the Leadbetter maneuvers (FIG. 29). The patient is placed on the fracture table as described above, except that the injured extremity remains free. It is grasped and held by the surgeon so that the hip and knee are flexed to 90 degrees and the former is in full external rotation and neutral adduction. In this position, strong traction is applied on the thigh. The extremity is then internally rotated to the limit and brought into moderate abduction as the hip and knee are extended. Reduction may be tested by the heel-palm test. The heel is allowed to rest on the open palm of the surgeon. If the fragments are reduced, the extremity remains in moderate internal rotation or, at the most, rotates quite slowly toward external rotation. Finally, the foot is secured to the foot piece so that the hip is held in full internal rotation and moderate abduction and the extremity in moderate traction.

Check roentgenograms in two planes are made following either method for reduction. Satisfactory reduction includes perfect apposition and alignment of the fragments in both views or slight valgus of the head in the anterior-posterior view with perfect reduction as seen in the lateral view. A highly desirable feature of reduction calls for the inferior cortical margin of the proximal fragment to rest on or within the adjacent cortex of the distal fragment (McElvenny; FIG. 30). Actually, some effort should be made to achieve this objective. At times it can be obtained by first applying enough traction to produce slight overreduction and then forcefully striking the thigh on the lateral side at the subtrochanteric level with the heel of the hand so as to jam the outer fragment toward and partially

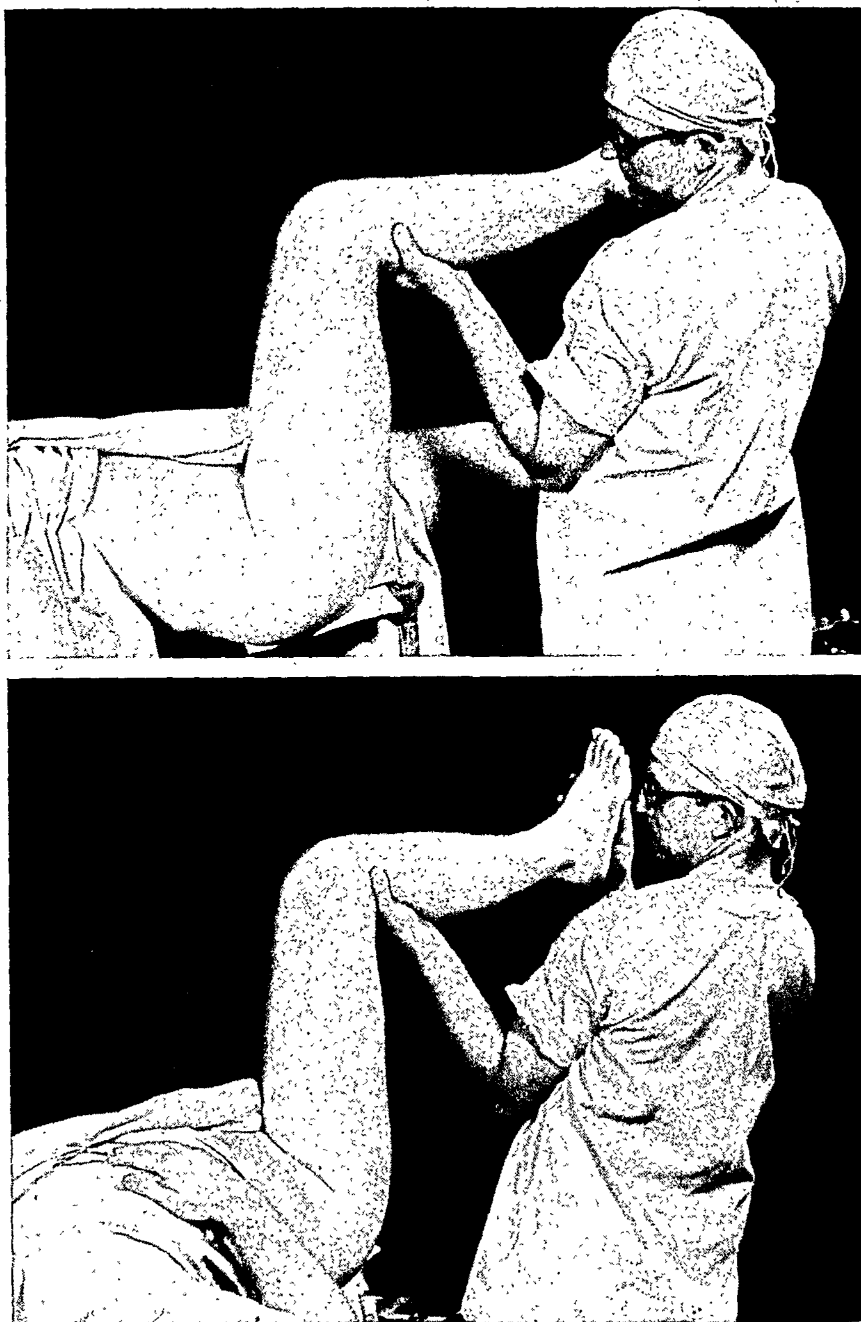


FIG. 29—*Leadbetter Maneuvers for Reduction of a Fracture of the Neck of the Femur.* (A) *Above.* The hip and knee are flexed to ninety degrees. As a preliminary to reduction, the hip is rotated internally and externally until some crepitus is elicited. This insures against impaction of the fragments in faulty position impeding reduction by manipulation. Strong traction is then exerted on the thigh in an upward direction. (B) *Below.* The hip is internally rotated while strong traction is being maintained.





FIG. 29—(C) *Above.* While the internal rotation and traction are maintained, the extremity is brought into extension and mild abduction. (D) *Below.* The heel-palm test. If the fracture of the neck of the femur has been reduced, the extremity will not fall into eversion. Usually a position of neutral rotation will be maintained and at the most the extremity will roll slowly into external rotation.



FIG. 30—*Intracapsular Fracture of the Neck of the Femur.* (A) Anterior-posterior view of pelvis showing intracapsular fracture of the neck of the left femur in a 63 year old lady. (B) Anterior-posterior and lateral (roentgenogram retouched for better visualization) showing excellent reduction of the fragments on the operating table. Note the slightly valgus reduction. Note the inferior cortex of the neck of the medial fragment is just inside the adjacent inferior cortex of the lateral or distal fragment. (C) Anterior-posterior and lateral views of the fragments stabilized with a triflanged (Smith-Petersen) nail. This fracture went on to solid bony union and the function of the extremity was completely restored.

under the inner. The reduction must be excellent as seen in the lateral view at the time this is done.

If check roentgenograms do not reveal satisfactory reduction of the fragments, additional efforts must be made until it is satisfactory. If several efforts fail, then an open reduction must be performed so that the fragments may be reduced under direct vision. Even this reduction should be verified by roentgenograms before insertion of the internal fixation. This technic is discussed later.

Types of Internal Fixation: Several acceptable means of fixation of the fracture are available. These include the Smith-Petersen Nail (cannulated and noncannulated), Moore pins, Knowles pins, Moriera lag-screw, Jewett type nail-plate, Pugh nail and others. All are designed to provide stabilization of the fracture without external fixation and to permit some active exercise of the extremity. By far the most commonly used is the cannulated Smith-Petersen nail and this technic, therefore, will be described. The same technic in general is employed for fixation with a Jewett type nail-plate. In addition, the technic for the use of Knowles pins will be described since these at times afford distinct advantages as in impacted fractures.

Smith-Petersen Triflanged Nail (FIG. 2N): This nail ideally is placed as vertically as possible yet it should penetrate the center or lower half of the femoral head after skimming along the calcar femorale. In the lateral projection, the nail should be placed centrally although it is acceptable to have the nail enter the posterior half of the head. The poorest position for the nail is obtained when it comes to rest in the superior and anterior quadrant of the head. The ideal depth of penetration brings the tip to within ⅛ inch of the articular cartilage. The nail should be of sufficient length to allow for the base to protrude from the femoral cortex for ½ to ⅝ inch. In this way the flanges maintain a good purchase in the cortex of the bone.

When satisfactory reduction of the fracture has been secured the subtrochanteric region of the femur is exposed through a lateral incision. A 3⁄16 inch drill hole is made in the cortex about 1½ to 1¾ inches below the vastus or trochanteric line (the highest point of origin of the vastus lateralis muscle) about midway between the anterior and posterior surface of the femur as it is held in internal rotation. This is really the most presenting point of the femoral cortex as it is viewed through the incision. The drill hole is fashioned in the general direction of the center of the femoral head which underlies where the femoral artery crosses the inguinal ligament (FIG. 31).

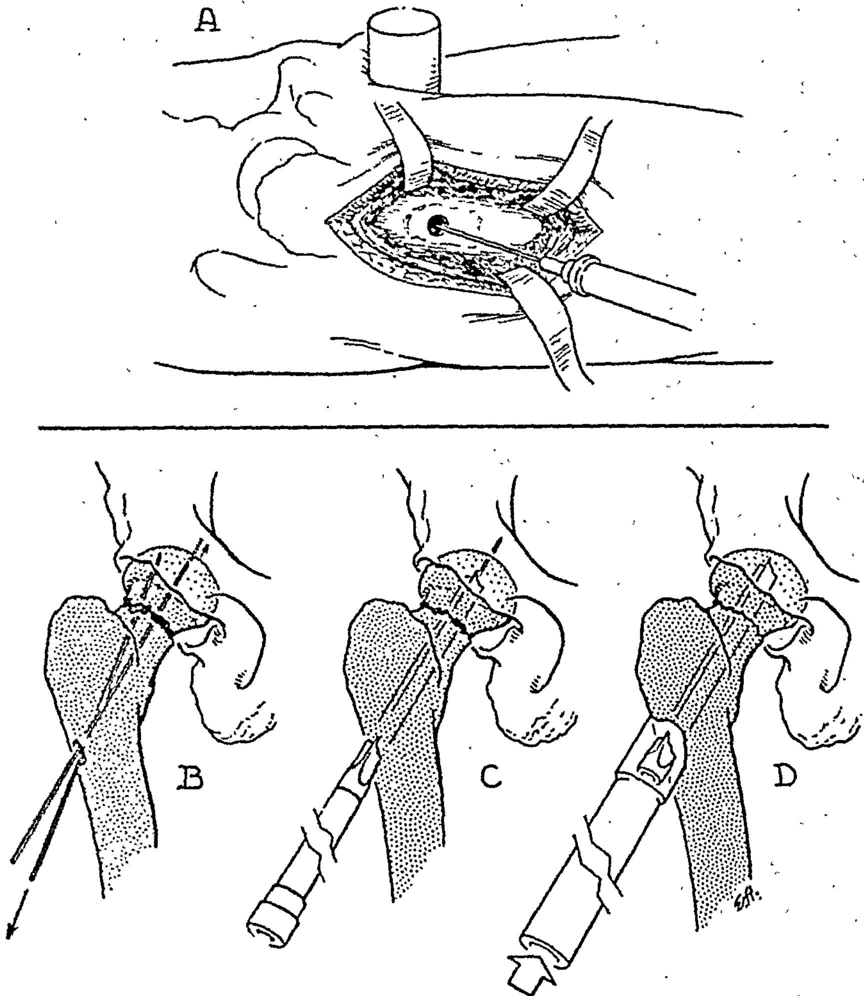


Fig. 31—*Technic of Internal Fixation of a Fracture of the Neck of the Femur with a Triflanged (Smith-Petersen) Nail.* (A) Exposure of cortex in subtrochanteric region of the femur through a short muscle-splitting incision. A hole one-fourth inch in diameter has been prepared at the estimated take-off point for the nail. This hole is usually prepared one and one-half to one and three-fourths inches below the vastus line (the highest point of origin of the vastus lateralis muscle on the lateral surface of the greater trochanter). (B) Two wires have been inserted. Following check roentgenograms, the inaccurately directed wire was withdrawn. The wire in the optimal direction was inserted farther so that the tip passes through the proximal fragment and is embedded in the pelvis. (C) A cannulated triflanged nail of adequate length has been passed over the guide pin. During this stage of the operation the protractor should be removed frequently to make certain that the guide pin is not being carried into the pelvis. (D) The nail has been inserted to within one-quarter inch of the articular cartilage. Note that a nail of sufficient length was selected to permit the bases of the flanges to still grip the lateral cortex. With an impactor the fragments are being impacted over the triflanged nail.

Several guide pins may then be inserted through the drill hole in slightly varying but the same general direction. In the position of maximum internal rotation of the thigh the femoral neck is about parallel to the floor as seen in the lateral projection. Guide pins, therefore, are placed in about this plane. Check roentgenograms in two planes are then made. The best placed pin is identified (if none is satisfactory all are redirected) and the others are removed. Using the known depth of penetration of the pin, a cannulated nail of appropriate length is selected. Using a standard protractor or driver which is cannulated, the nail is then inserted to the desired depth over the remaining guide pin. At times the guide pin can be carried forward through the femoral head and into the pelvis because a small piece of bone becomes impacted between the pin and the wall of the canal of the nail. Proper caution demands, therefore, that the protractor be removed several times during insertion of the nail so that the length of exposed portion of the guide pin can be verified.

Rotation of the femoral head as the nail enters it is a potential complication. A precaution against this may be taken by drilling an extra guide pin parallel to but at least ¾ inches away from (usually superior) the pin to be used as a guide for the nail. The extra pin is passed from the lateral cortex through the femoral head and actually into the acetabulum thereby securing the head. This is particularly advantageous in unstable fractures such as the vertical type (Pauwel's III).

Instead of several guide pins, a single pin may be inserted at a point known to be superior to the optimal point of take-off for the nail but, in general, parallel to the best direction for it. Such a guide pin then is actually in the upper half of the neck and head. Check roentgenograms are made. With the findings on these available, the $\frac{3}{16}$ inch drill hole for the final guide pin is made at the best take-off point for ideal direction of the nail. The guide pin to be used for the nail is then directed as indicated by the known relationship of the already placed pin. Additional roentgenograms may be made for verification. The original pin is drilled across the head into the acetabulum to act as the stabilizer. Then the nail of appropriate length is inserted over the pin in the proper direction. Actually, in many instances, information obtained from the roentgenograms showing the first "high" pin may permit the nail to be inserted and properly directed without a guide pin.

After the nail has been inserted to the calculated ideal depth, more check roentgenograms are advisable. Based on the findings, the nail is driven in farther or extracted a bit. Finally, all guide pins are removed. Then, with all traction on the extremities released, the outer or neck fragment is firmly impacted into the inner or head fragment by firmly striking a hallow impactor placed over the protruding base of the nail.

Jewett Type Nail-Plate (FIG. 2H): At this time, an increasing tendency exists in many clinics toward the use of this type nail, originally designed for trochanteric fractures, for internal fixation of fractures of the femoral neck. This method affords the theoretic advantage of firmer fixation of the base of the nail to the femoral cortex and prevents extrusion of the nail. On the other hand, if some absorption of bone takes place at the fracture line, the fixed nail may hold the fragments apart particularly if the femoral head is so hard as to prevent further penetration of the nail. If it is soft and absorption is excessive, the nail may penetrate into the acetabulum.

The technic of insertion is similar to that used with this nail-plate in trochanteric fractures. (p. 109). The nail is inserted less vertically than a Smith-Petersen nail and more directly along the center of the neck of the femur with the plate parallel to the femoral cortex to which it is fixed by screws.

Knowles Pins (FIG. 2P): These are drilled from the subtrochanteric region of the femur up the canal of the neck into the head in about the same manner in which guide pins are inserted. The pins should parallel each other. Three pins inserted with a triangular take-off design or four pins in a square take-off may be used.

Selection of pins of the best length is not easy but it is easy to remove a pin and replace it with another if the decision is made before the first pin is inserted all the way. Actually, frequent check roentgenograms are necessary to verify length and direction of the several Knowles pins. Placement of the pins so that the points do not converge toward the center of the head is difficult. In spite of these technical problems, Knowles pins can be inserted parallel and, therefore, the impacting lag effect of each can be accumulative. In many ways Knowles pins appear preferable to the Smith-Petersen nail for internal fixation of fractures of the femoral neck. They are certainly preferable for internal fixation of impacted fractures (FIG. 32D AND E).

Pitfalls and Precautions

1. Excellent reduction of the fracture is the keystone of successful management.
2. Do not hesitate to remanipulate if the check roentgenograms show inadequate reduction.
3. Do not accept a varus (downward) position of the head as seen in AP view or anterior angulation of the fragments (posterior tilt of the head) as seen in the lateral view.
4. Avoid a high take-off of the nail; a low take-off and a more vertical direction of the nail are desirable.
5. Make certain that the femoral head does not tilt as the nail enters it. (Drill a second guide pin across the fracture line and really into the acetabulum superior to the line of the nail before inserting the nail.)
6. Impact the fragments after satisfactory placement of the nail.
7. Do not permit any weight-bearing before some union of the fragments.

Open Reduction: If satisfactory closed reduction cannot be achieved, the hip joint must be opened so that intervening capsule or chips of bone may be removed and the fragments reduced accurately. Either a Watson-Jones or Cubbins incision may be used to expose the anterior capsule which is opened by a cruciate or trap-door incision. The joint is cleaned of blood clot and loose chips of bone. The fragments are reduced by manipulation of the extremity aided by direct instrumental leverage. Adequate traction on the extremity and full internal rotation of the thigh are essential. The latter position makes it quite difficult to be certain that reduction is accurate even with the joint open; therefore, check roentgenograms are essential before internal fixation of the fracture. The technic of insertion of internal fixation is the same as that described under closed reduction.

Impacted Fractures: In most fractures throughout the skeleton, impaction of fragments insures eventual union. This is not so in fractures of the femoral neck. Fractures firmly impacted with the head in normal or slight valgus as seen in the anterior-posterior view and in excellent apposition and alignment as seen in the lateral view are likely to hold so that ultimately the fracture unites if the patient is kept inactive in bed or at most in a chair for four to six weeks. Those impacted in all other positions are almost certain to become disimpacted. Many will hold for one to two weeks and then become loose. All fractures impacted in other than excellent position, therefore, should be treated as if they were not impacted. Under anesthesia, with the patient on the fracture table, the impaction is broken up

by manipulation of the thigh as a preliminary step to reduction of the fragments by the technic described above (p. 92).

Those fractures impacted in excellent position which includes a slight valgus reduction deserve internal fixation. Internal fixation of impacted fractures insures that reduction will be maintained while the patient is turned freely in bed and allowed up in a chair promptly. Moreover, ambulation in a walker or with crutches is permissible within a few days if the patient is at all self sufficient.

Either Knowles pins or a Smith-Petersen nail may be used to provide internal fixation (FIG. 32). The former are recommended for impacted fractures particularly as their insertion in no way disturbs the impaction. On the other hand, as a Smith-Petersen nail is advanced across the fracture line, the fragments can be driven apart.

Hip Endoprosthesis: In many but still carefully selected patients with fractures of the neck of the femur, their interests will be best served by primary excision of the femoral head and replacement by an intramedullary type hip prosthesis (Fred Thompson type; FIG. 2J) in preference to closed reduction and internal fixation of the fracture. Increasing clinical experience substantiates this apparently radical approach to this complex problem (FIG. 33).

In general, patients for whom this method of management is chosen are in the latter decades of life, usually over or physiologically over 70 to 75 years of age. In this age group, the incidence of non-union with closed reduction and internal fixation well done has been relatively high, at least 20 to 25 per cent. To obtain a united fracture, a period of four to eight months of freedom from weight-bearing (usually a wheel chair existence) is required which is quite a problem to attending relatives. Such inactivity predisposes to complications of all sorts including atrophy and weakness of the musculature of the lower extremities. Of those which do unite, a high percentage (approximately one-third) develop avascular necrosis with resulting painful hips. Fractures of the neck of the femur remain unsolved fractures for which closed reduction and internal fixation have not supplied an entirely satisfactory answer particularly in this age group, the eighth and higher decades. The life expectancy in this group hardly exceeds the period of time required to determine if nailing will give a satisfactory hip.

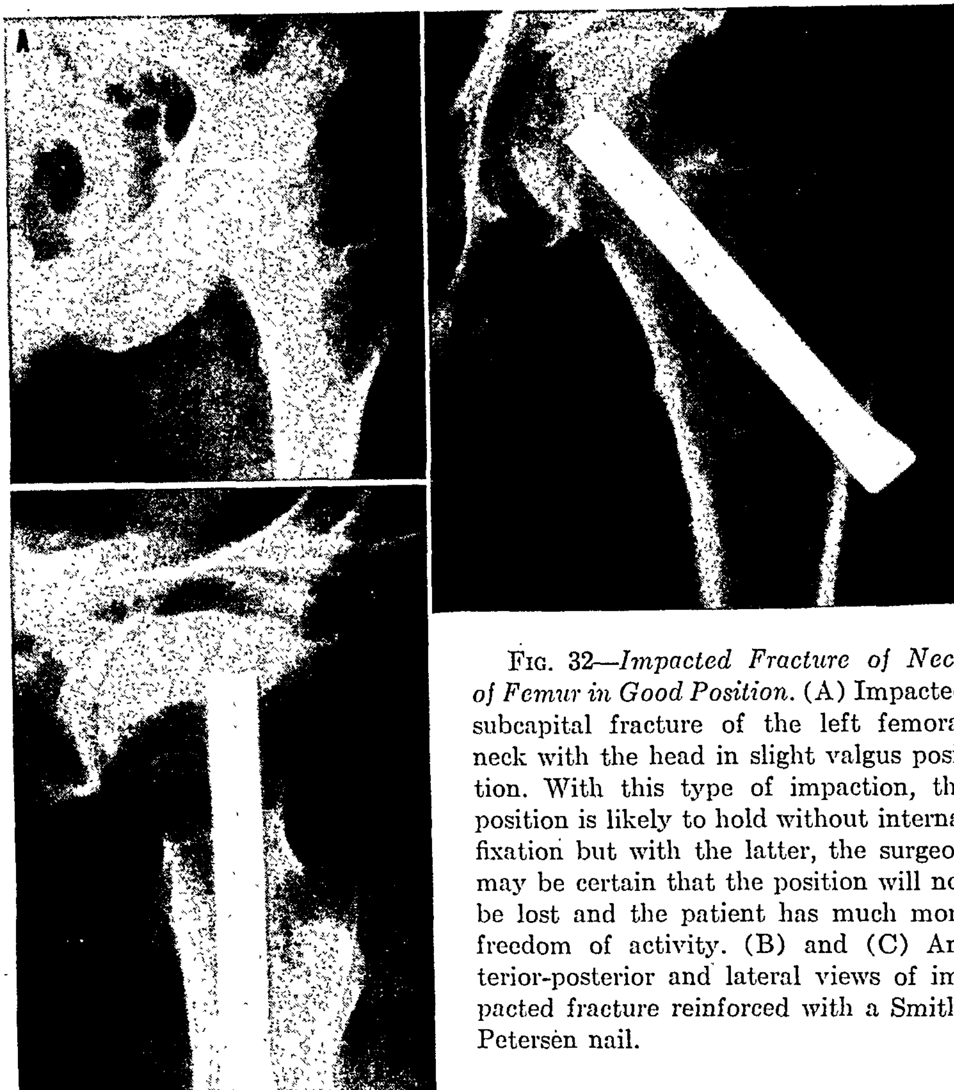


FIG. 32—*Impacted Fracture of Neck of Femur in Good Position.* (A) Impacted subcapital fracture of the left femoral neck with the head in slight valgus position. With this type of impaction, the position is likely to hold without internal fixation but with the latter, the surgeon may be certain that the position will not be lost and the patient has much more freedom of activity. (B) and (C) Anterior-posterior and lateral views of impacted fracture reinforced with a Smith-Petersèn nail.

Primary implantation of a hip prosthesis obviates many of these problems. Inactivity is minimized. Within four or five days of operation, the patient may bear full weight and begin walking. Of course, a walker, chair or manual help is usually necessary for a few days at least. Most patients, however, may walk unaided or with a cane at the end of 10 to 12 days and may leave the hospital. Moreover, the surgery required for insertion of the prosthesis is very little if any more strain on the patient than mere closed reduction and internal fixation. He or she may be turned in bed and placed in a chair



Fig. 32—(D) and (E) Anterior-posterior and lateral views of a mildly impacted fracture of the femoral neck in good position. (F) and (G) Anterior-posterior and lateral (really an oblique) views showing the fragments fixed in reduction with four Knowles pins.

as promptly and as readily with the former as with the latter operation.

Primary implantation of a hip joint endoprosthesis does not, of course, give as good a hip as would be obtained if the fracture were nailed and united promptly. It does, however, give a good hip quickly. In the group for which it is recommended, subsequent activity following a fracture of the neck of the femur is most likely to be minimized and the hip with a prosthesis will be adequate for the anticipated activity. The patient may or may not want to use a cane. Some minimal discomfort is to be expected from time to time,

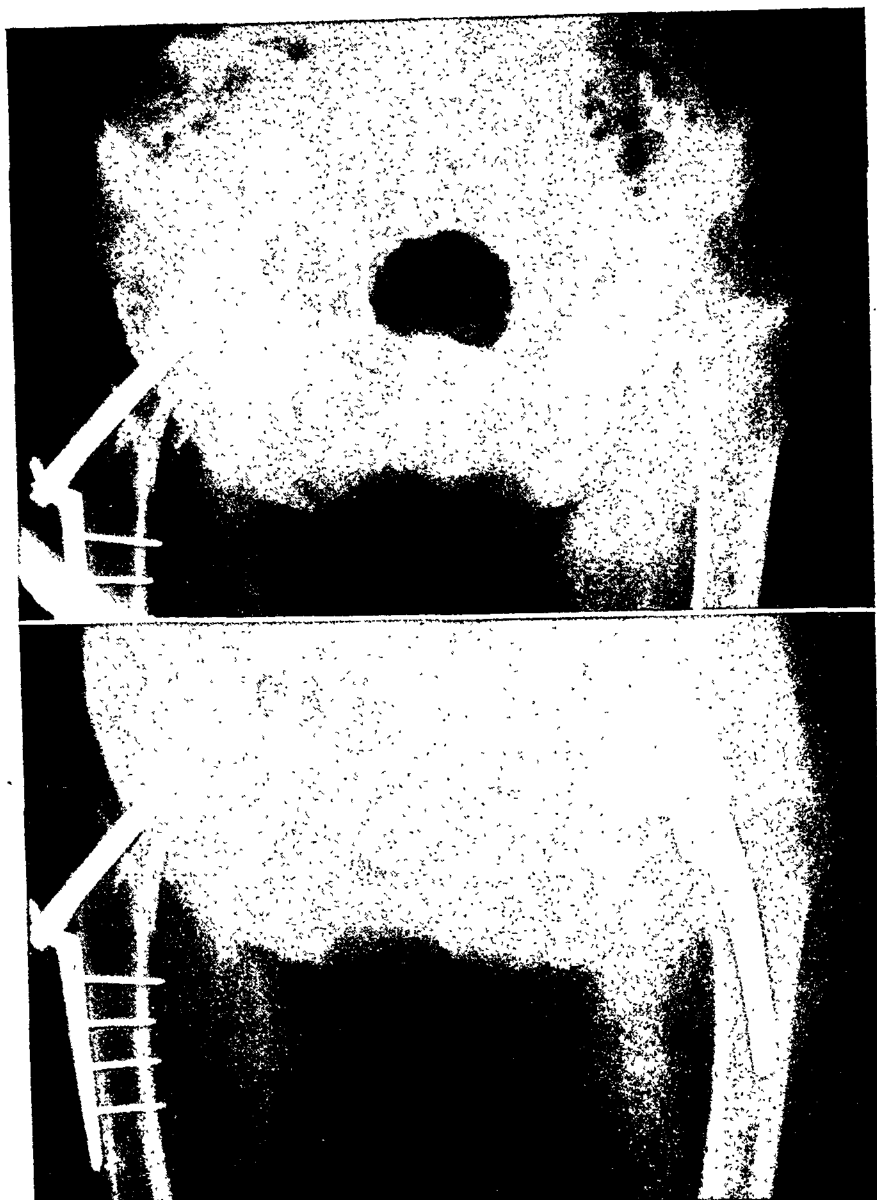


FIG. 33—*Intracapsular Fracture of the Neck of the Femur Treated by Replacement with a Prosthesis.* (A) *Above.* Anterior-posterior view of pelvis showing intracapsular fracture of the neck of the left femur in an 89 year old lady. Note that she survived a trochanteric fracture of the other femur sustained eight years previously which was treated by open reduction and internal fixation with a McLaughlin nail. (B) *Below.* Anterior-posterior view showing that the femoral head has been removed and replaced by a Fred Thompson hip joint endoprosthesis. Note that with this prosthesis full length of the femoral neck has been restored. This is important in avoiding postoperative dislocation of the head portion of the prosthesis and in restoring function of the hip.

especially on the first few steps after prolonged sitting. On the whole, the clinical result is quite likely to be highly satisfactory.

Of course, age alone may be a good guide but hardly an exact criterion on which to determine whether to select primary prosthesis implantation over closed reduction and internal fixation. A better way to state the basis for choosing between these probably is to say that if the patient is in adequate physical condition to withstand the latter procedure, several months of wheel chair existence and then a second operative procedure, if necessary, for a delayed implantation of a prosthesis, then closed reduction and internal fixation should be carried out. If the answer is no, however, primary implantation of a hip joint prosthesis is probably preferable. In this connection it should be appreciated that the clinical results with primary prosthesis implantation are superior, in general, to delayed prosthesis implantation as muscle tone and strength and confidence of the patient have not been lost.

Technic: The procedure may be carried out through either an anterior, posterior or a posterolateral (Gibson) approach. Each has certain advantages and disadvantages. All in all, the anterior approach has proven quite satisfactory and is recommended. The patient is placed on a standard operating table with a "kidney rest" at the level of the anterior-superior spines. A sheet is folded to a width of about 4 inches and looped through the perineum with the ends presenting over the patient's shoulder. This will be used for countertraction later during reduction.

The anterior incision is really the longitudinal portion of the standard Smith-Petersen anterior approach to the hip joint. With the sartorius and the rectus femoris muscles retracted medially and the tensor fascia femoris laterally, the hip joint capsule is exposed and cleaned as well as possible of fatty and areolar tissue in all directions with a broad periosteal elevator. The reflected head of the rectus femoris is identified and sectioned leaving enough of a stump to permit repair. In some cases, a small portion of the origin of the tensor fascia femoris is stripped from the ilium to give better exposure but it seldom is necessary to cut and strip the fascial origin from the iliac crest.

The hip joint capsule is then opened widely usually by a T or trapdoor (I) incision bringing the fracture site and femoral head into view. At this point elevation of the kidney rest to provide hyper-

extension of the hip is highly advantageous. The femoral head is then removed with a corkscrew instrument for that purpose. The ligamentum teres is usually avulsed from the head so that it then hangs in the acetabulum. It is easily excised at its base.

The stump of the neck is then prepared to receive the prosthesis so that the collar of the latter will fit flush against bony cortex. Loose chips are removed. Irregular protruding bits of bone are ronguerred away. The design of a Fred Thompson type prosthesis demands that the stump of the neck be made vertical or like a Pauwel's Type III fracture for a good fit and, therefore, in many fractures some bone must be removed at the calcar femorale. Also, in this area, it is wise to bite away a small U or V of bone to receive the tip of the prosthesis. This point of entry may be deepened by curretting the adjacent cancellous bone but preparation of a track with a reamer for the intramedullary portion of the prosthesis is neither necessary nor wise.

A prosthesis is selected with the head portion only slightly smaller than the femoral head which was removed. Usually a 1¾ inch diameter is used in females and a 1⅞ inch in males. With the thigh held in full external rotation which causes the stump of the neck to face anteriorly, the prosthesis is inserted and tapped downward with the heel of the hand. Every precaution is taken to insure that the ongoing stem follows down the medullary canal of the femur. Manual traction on the extremity by an assistant facilitates the insertion of the prosthesis as it helps to get the head portion distal to the upper corner of the incision. When the prosthesis has been inserted with the hand so that only an inch or so more advancement of it is needed, gentle taps with the mallet on the special driver may be used to seat it finally. During insertion, an assistant must constantly observe the region of the calcar femorale for the first sign of a split, a complication to be avoided at all costs. Any beginning split means that the prosthesis must be removed and redirected and usually the U or V on the calcar must be deepened a bit. As part of the last step of insertion of the prosthesis, any high points on the stump of the neck are removed with a chisel to allow the best possible fit with the collar of the prosthesis.

When the prosthesis is well seated in the femur, the acetabulum is cleaned and the hip is reduced. The elevated kidney rest is first lowered. Countertraction is provided by an unsterile assistant pulling on the ends of the sheet previously looped through the perineum and

by tilting the table so the head is down. An assistant provides strong traction on the leg followed by some abduction and finally full internal rotation while the operator pushes the head of the prosthesis into the acetabulum. At times, a bone skid may be used to aid reduction. The judicious use of succinylcholine chloride (Anectine) by a competent anesthesiologist to provide full muscular relaxation can be most valuable during reduction. Its use minimizes danger of fracture of the upper femoral shaft or roof of the acetabulum.

The sectioned reflected head of the rectus and the capsule are repaired and the wound is closed. An effective pressure dressing tends to minimize serum collections and aids in healing.

Postoperatively, the patient may be turned freely and allowed to sit on the bedside or in a chair at will. Within a few days, walking in a walker or with crutches is permitted and activities are rapidly increased within the patient's tolerance.

Pitfalls and Precautions

1. Select patients with caution for this method of management. It is a radical approach to this injury.
2. Prepare the stump of the neck carefully; avoid removal of too much bone. To foreshorten the neck too much is irremedial and predisposes to dislocation later.
3. Do not broach the canal excessively and make for a loose fit.
4. Select a prosthesis only slightly smaller than the femoral head which was removed.
5. Insert the prosthesis with caution; do not "hammer it home"; avoid at all costs, splitting of the upper femur both during insertion of the prosthesis and reduction of the prosthetic femoral head.
6. Make certain the stem of the prosthesis travels down the medullary canal and does not perforate the cortex.
7. Careful hemostasis and a good pressure dressing after a good layer closure are important precautions against wound sepsis.

Fractures of the Trochanteric Region of the Femur

Fractures of the trochanteric region include both intertrochanteric and subtrochanteric fractures. Continuous traction methods for these fractures give a very high percentage of union in good position but such methods carry prolonged hospitalization and bedrest, a high incidence of bed sores, bladder complications, pneumonia and thrombophlebitis and all in all, a high mortality. Moreover, at best, knee motion becomes restricted and the musculature of the extremity particularly and of the patient as a whole becomes reduced in strength.

These undesirable sequelae can be minimized or obviated by open reduction and internal fixation of the fractures. Immediately post-operation, the patient may be turned to either side frequently and placed in a chair for increasing periods daily. The younger and stronger patients may use crutches or a walker within a few days and practically all may leave the hospital after 10 to 14 days. As a result the incidence of complications and the mortality are markedly reduced. Moreover, better reduction is obtained. It is reasonable to state, therefore, that open reduction and internal fixation are indicated for practically all of these injuries. The poorer the general condition of the patient, the more the indication for operation in an effort to *avoid life-endangering complications and to preserve the life of the patient,* not to secure union of the fracture.

The timing of operation in these fractures is important. Operation should not be postponed for days after injury but neither is it necessary as an emergency. The patient should be allowed to recover from the impact of injury. Few actually develop the clinical syndrome of traumatic shock but all are adversely affected by the injury. Series of cases from several areas of the country have been reported to show a lower mortality rate among those operated on after 24 to 48 hours following injury than in those given operation as an emergency. The patient should be evaluated thoroughly and any appropriate corrective measures instituted before operation.

Type of Internal Fixation: All fractures in the trochanteric region require a nail-plate and screw combination for adequate stabilization of the fragments. Several designs are available. These include the Jewett type nail, Neufeld nail, Smith-Petersen nail with a Thornton plate, McLaughlin nail (FIG. 2) and others. All come with varying lengths of nails and plates. In our opinion the Neufeld nail is the most easily inserted, the Smith-Petersen nail and separate plate the most difficult. The Vitallium Jewett nail appears to be the strongest. We recommend it for subtrochanteric fractures (these require a long plate so that at least three screws are inserted below the level of the fracture) and trochanteric fractures in young males or old males with Parkinsonian rigidity. The Neufeld nail is adequate for all others (FIG. 34).

Technic: In most trochanteric fractures reduction is obtained on a standard fracture table. By moderate traction and abduction of the extremity with the thigh in neutral rotation (the patella points up-

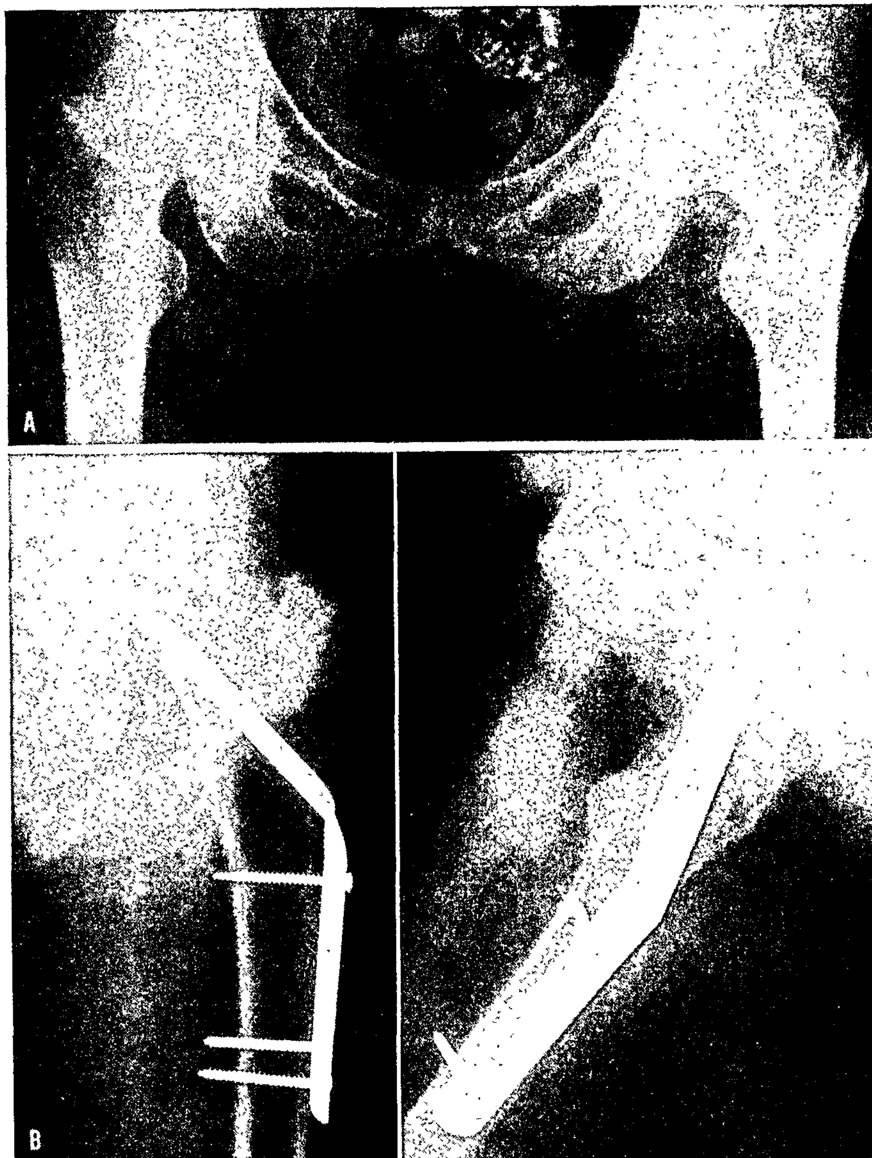


FIG. 34—*Trochanteric Fracture of the Left Femur.* (A) Anterior-posterior view of pelvis showing typical trochanteric fracture of the left femur. (B) and (C) Anterior-posterior and lateral views of the united fracture after open reduction and internal fixation with a Neufeld nail.

ward) adequate reduction is easily achieved in most cases. The neutral rotation is in marked contrast with the full internal rotation in fractures of the femoral neck. In some, usually the more comminuted fractures, direct manipulation of fragments after operative exposure is necessary before adequate reduction is obtained. In subtrochanteric fractures satisfactory closed reduction is unusual.



Fig. 34—(D) Anterior-posterior view of pelvis showing trochanteric fracture of left femur.

Rather, as a rule, a true open reduction is performed after exposure of the fragments.

Adequate exposure for internal fixation of fractures in these groups may be obtained through a lateral incision over the upper thigh. The incision in the skin must always be longer than the plate of the nail to be used. The vastus lateralis should be reflected forward from close to the linea aspera rather than split in the line of the skin incision.

The first objective after exposure of the femur is to select the proper take-off point for the nail. This usually is about 1 inch below the vastus line (the highest point of origin of the vastus lateralis on the base of the greater trochanter) and slightly posterior to the most presenting area of the femoral shaft. This apparently posterior take-off is essential because in the neutral degree of rotation of the femur usually necessary for the best reduction of these fractures,



FIG. 34—(E) and (F) Anterior-posterior and lateral view showing fixation of fracture in excellent reduction with a McLaughlin nail-plate combination.

the neck of the femur points slightly forward from lateral to medial rather than parallel to the floor.

At the selected take-off point, a drill or guide wire may be inserted up the femoral neck. Check roentgenograms are then made to verify that the appropriate take-off point has been selected and as an aid in selecting a nail of the best length. With increasing experience this step may be omitted. At the take-off point, a hole is created in the cortex with a ½ inch burr or drill and this hole may be enlarged with a rongeur. The opening in the cortex should easily receive the nail without force. In the use of nail-plate for fixation of trochanteric fractures, snug fixation of its angle in the cortex is not necessary or advisable.

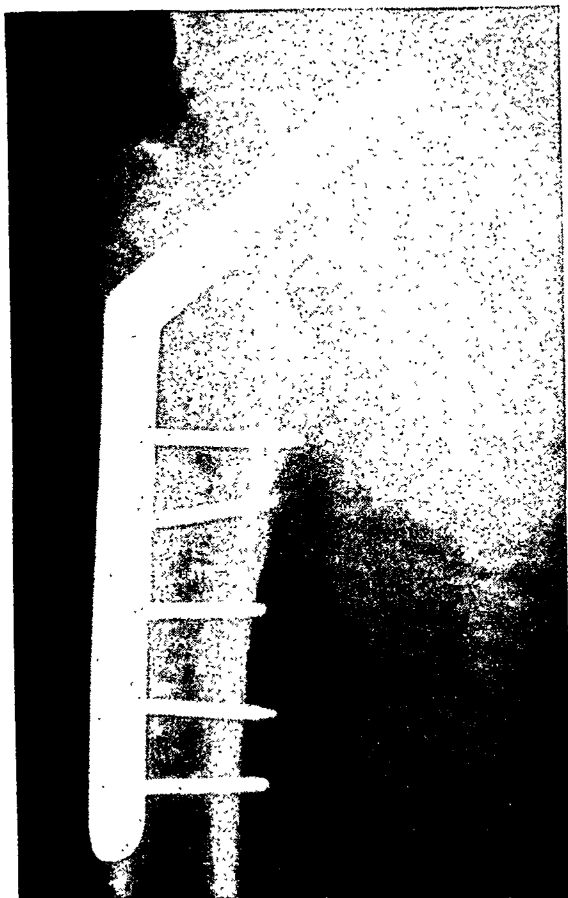


FIG. 35.—*Problem of Medial Drift of the Nail in Subtrochanteric Fractures.* (A) A subtrochanteric fracture was well nailed but strong pull of the adductor muscles caused a medial drift of the shaft which in turn advanced the nail through the femoral head and into the acetabulum.





FIG. 35—(B) A subtrochanteric fracture which typically presents this problem. (C) The method used in fracture shown in B in an effort to prevent medial drift of the shaft and intra-acetabular protrusion of the nail. Actually, the most superior screw should be much longer and at times a Knowles' pin can be used to advantage.

The usual nail-plate forms an angle of 130 degrees. If the take-off point is properly located, such a nail will travel up the middle of the femoral neck and the plate will come to lie flush against the upper femoral shaft. In fact, the nail is inserted and advanced with the plate held parallel to the femur so that it will do so. Aided by the protractor the nail is inserted and advanced so that it points somewhat anteriorly with merely the force of the hand. If its direction is accurate, advancement is easy until the point reaches the substance of the head at which point only ½ to ¾ inch of the nail remains uninserted. Then check roentgenograms should be made. If indicated the nail is withdrawn and redirected. Perhaps a different take-off point must be selected. Finally, the nail is fully inserted using a mallet and the plate is fixed to the shaft with screws of the length necessary to penetrate both cortices of the femur.

Comminuted trochanteric fractures which include a subtrochanteric line of fracture and high near-transverse subtrochanteric fractures demand special consideration. In these the lateral end of the line of fracture at the subtrochanteric level enters the desired take-off point for the nail so that it takes no purchase in the major distal fragment. The nail is fixed to the latter, therefore, only by the plate and screws. The shaft then is merely held in approximation by the nail in the neck. Under these circumstances, continuing pull of the strong adductor magnus is likely to pull the shaft medially advancing the nail through the femoral head and into the acetabulum (FIG. 35A). In these complex fractures, the internal fixation must include not only the nail-plate but something to fix the shaft to the trochanteric region. This can be accomplished by a bone plate (the Moe Plate is ideal), a special nail or loops of wire (FIG. 35B AND C).

Subtrochanteric Fractures: In subtrochanteric fractures, comminuted or oblique, the principal line of fracture usually extends from about the lesser trochanter medially to a point a few inches lower laterally. For these, the plate portion of the nail-plate must be sufficiently long to permit at least three and preferably four screws to enter the distal fragment below the line of fracture (FIG. 36).

With these injuries, a true open reduction is performed. The fragments are exposed through a long lateral incision. The nail is inserted up the neck of the femur by the usual technic so that the plate fits flush against the lateral cortex of the upper fragment. Then the fracture is reduced under direct vision utilizing strong traction,



FIG. 36—*Comminuted Subtrochanteric Fracture of the Right Femur.* (A) Anterior-posterior view of pelvis showing comminuted subtrochanteric fracture of the right femur with medial displacement of the distal fragment.

rotation of the lower fragment as seems best and direct leverage on the fragments. As a rule, considerable external rotation of the lower fragment will be required for accurate reduction of the fracture. Using bone-holding clamps to maintain reduction, the plate is fixed to the shaft by screws inserted parallel to each other for the maximum holding strength. At times, additional transfixion screws may be inserted across the fracture line for additional fixation (FIG. 37). Often a large comminuted fragment must be fixed to the shaft by transfixion screws before the major fragments are reduced and the plate fixed to the shaft.

Pitfalls and Precautions

1. Avoid excessive delay in surgery; do not allow the medical consultant to talk you into delay unless he *knows* he can not only improve the patient's ability to withstand anesthesia and surgery but also, avoid deterioration in the general condition during the delay.
2. Avoid excessive traction and excessive internal rotation during efforts at reduction.
3. Use a nail of adequate strength so as to avoid bending and breaking at or near the angle.



Fig. 36—(B) and (C) Anterior-posterior and lateral views after open reduction and internal fixation with a vitallium Jewett-type nail. The overall restoration of anatomy was good but comminution prevented jigsaw puzzle reduction. The lesser trochanter remains displaced medially. From a functional standpoint, this is of no significance. Note that the screws fixing the plate to the shaft parallel each other and penetrate the inner cortex. Also note that a nail with a long plate was used.

4. Avoid a too anterior take-off of the nail which prevents adequate anterior directing of the nail.
5. Adequately enlarge the opening for the nail on the lateral cortex so as to avoid new lines of fracture, particularly a subtrochanteric fracture line.
6. The nail should not be so long as to reach the articular cartilage of the head. With absorption at the fracture line, the nail may penetrate farther and even through the head.
7. In comminuted trochanteric or high subtrochanteric fractures, use some means of avoiding postoperative medial shift of distal fragment and resulting excessive penetration of the nail.
8. In true subtrochanteric fractures, insert the nail properly in the upper fragment before reducing the fracture.



FIG. 36—(D) and (E) Anterior-posterior and lateral views made four months after operation showing the fracture going on to solid bony union. An excellent end result was obtained.

Fractures of Posterior Acetabulum Associated with Posterior Dislocation of Hip

A fracture of the posterior portion of the acetabulum is frequently associated with posterior dislocation of the hip. As the femoral head leaves the joint, it drives with it a portion of the acetabulum. This combination of injuries is a frequent result of automobile collisions. The knee of a front seat occupant forcibly strikes the dashboard (hence the term, "dashboard dislocation") producing the dislocation and fracture.

As the dislocation of the hip is reduced, the acetabular fragments frequently fall into good reduction. The important consideration concerning this fracture, however, is the size of the fragment or fragments and the potential defect in the acetabular wall. If the fragments are small they may be ignored even though they have not

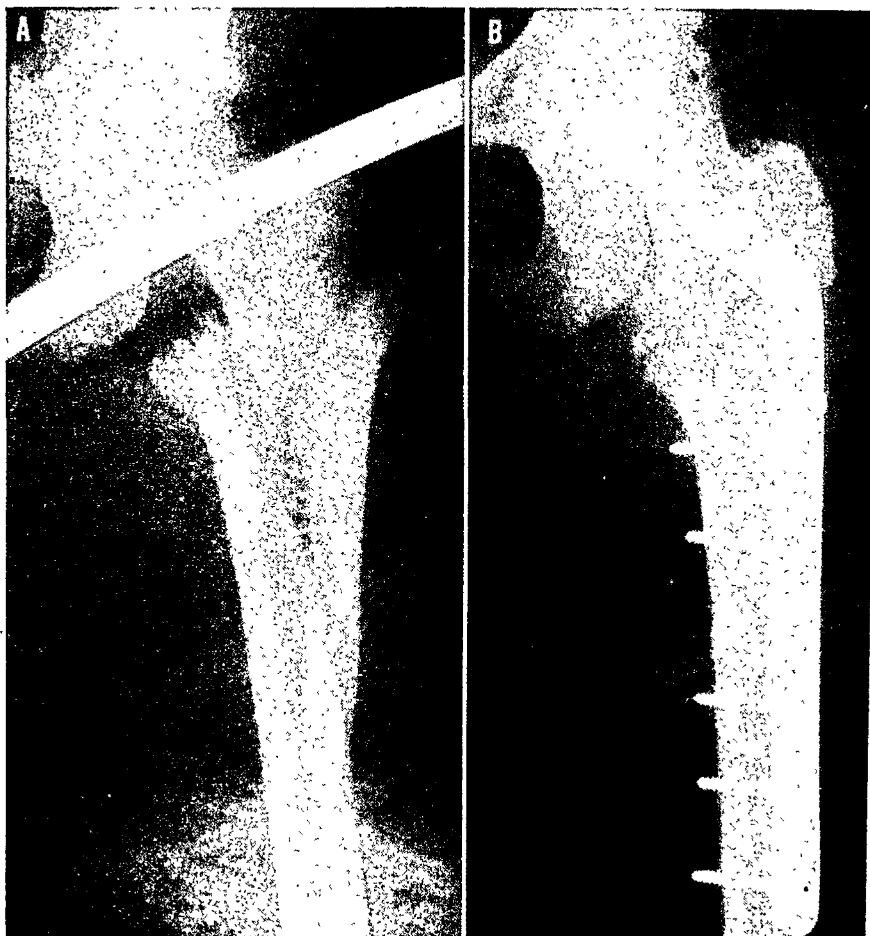


FIG. 37—*Comminuted Subtrochanteric Fracture of the Left Femur with a Line of Fracture Extending down the Shaft for Several Inches.* (A) Anterior-posterior view of comminuted subtrochanteric fracture of left femur. (B) and (C) Anterior-posterior and lateral views after open reduction and internal fixation with a Jewett-type nail supplemented by separate screw fixation of the vertical split in the upper portion of the shaft. Note the unusual degree of valgus of the femoral neck which increased the difficulties of the operative procedure. (D) Anterior-posterior view showing united fracture in excellent position.

gone back into excellent reduction. On the other hand, if a single fragment or a group of fragments comprise a significant portion of the posterior acetabulum, then they are of extreme importance (FIG. 38).

If excellent reduction of these fragments is not obtained at the time the dislocation is reduced, then obviously, open reduction and internal fixation is indicated. Even if they do fall into good reduction, the danger of subsequent displacement and even dislocation of the head of the femur resulting from the continuous backward pressure



FIG. 37—(C) and (D) *See legend, facing page.*

of the head of the femur against the fragments dictates that they be stabilized in reduction at operation.

Reduction of the dislocation is an emergency. The longer the femoral head remains dislocated, the greater the chances of avascular necrosis. Open reduction of the posterior acetabular fragment is not an emergency but should be carried out within a few days of injury.

Technic: The surgical approach is posterior, not anterior. With the patient face down, an oblique incision is made from midway between the posterior superior and inferior spines to the base of the greater trochanter (FIG. 39). It may then be extended down the side of the thigh for 3 or 4 inches for better exposure when the patient



FIG. 38—*Fractures of the Posterior Acetabulum Complicating Dislocations of the Hip.* (A) Fracture of the posterior acetabulum associated with posterior dislocation of the right hip. The dislocation of the hip has been reduced without adequate reduction of the large fragment of posterior acetabulum. Note the defect in the posterior acetabular wall behind the head of the femur. Compare the outline of the margin of the posterior acetabulum on the right with that on the left. (B) Posterior dislocation of the right hip associated with comminuted fracture of the posterior acetabulum. In this instance the fracture extends intrapelvically. (C) The femoral head has been reduced and the acetabulum has been reconstructed. The large fragments of posterior acetabulum have been stabilized in position with two screws and a threaded pin cut off as a screw. Note that the screws and pin penetrate the inner cortex of the pelvis for better stability.

is large and heavy. The dissection is carried through the gluteal fat exposing the fascia over the gluteus maximus which is incised. Laterally, this incision splits the tendon and an extension downward partially severs it. The fibers of gluteus maximus are separated in the line of incision. If the latter has been placed properly, only a few small veins and arteries require ligation and no essential blood supply is sacrificed.





FIG. 38—(D) Posterior dislocation of the left hip complicated by fracture of the posterior acetabular wall. Actually the femoral head remains subluxed posteriorly. The arrow points to the double line of density superior to the femoral head and the projecting portion of the bony fragment. This is the type of fracture-dislocation of the hip which is easily overlooked. (E) Fragment of posterior acetabulum has been reduced at open operation and stabilized with two screws.

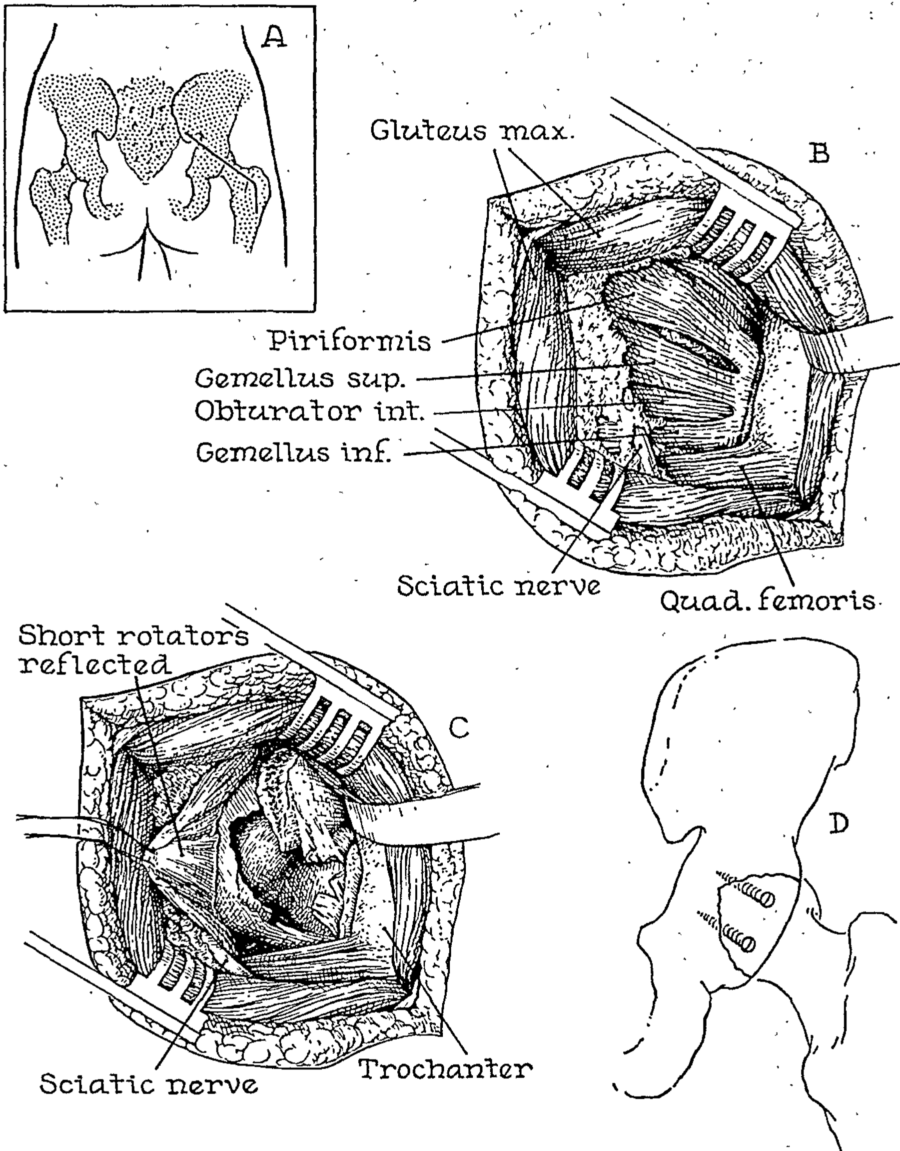


FIG. 39—*Technic of Open Reduction of Fractures of the Posterior Wall of Acetabulum.* (A) The line of the skin incision across the buttock and turned downward at the posterior margin of the greater trochanter. (B) The gluteus maximus muscle has been split in the line of its fibers and its tendon partially severed to expose the short external rotator muscle groups. (C) The piriformis, the gemelli, and the obturator internus tendons have been severed near their points of insertion and folded medially. In this way the sciatic nerve is protected and the posterior portion of the hip joint comes into view. The displaced fragment of acetabulum and the defect into which it will be replaced as well as the underlying femoral head are illustrated. (D) Schematic drawing of the replaced fragment fixed in position with two screws.

Deep to the gluteus and medially runs the sciatic nerve to be safeguarded. The tendons of the short external rotator group are identified close to their insertion in the greater trochanter where those of the piriformis, both gemilli and the obturator internus are severed. The free ends of the severed tendons are sutured together. Then, this mass is folded medially over and protecting the sciatic nerve. With minimal dissection the rent in the capsule and the displaced acetabular fragment are isolated. Usually, some additional incision in the capsule is necessary for adequate exposure. If more room is needed, a portion of the tendon of the gluteus minimus may be sectioned.

The interior of the hip joint and femoral head are inspected and any loose bone chips are removed. The raw surface of the fracture on the pelvis and that of the displaced fragment (or fragments) are cleaned. The latter is rotated into reduction avoiding as much as possible separating it from any soft tissue attachments. The fragment is then stabilized in reduction by one, two or more screws which ideally penetrate the inner pelvic cortex (FIG. 38).

Of course the screws must not penetrate the articular surface. A good precaution is to insert the first screw through the drill hole to the line of fracture, then displace the fracture so as to visualize the tip of the screw perforating through the raw fracture surface. When the fracture is reduced, the screw is advanced into the pelvis. Additional screws are inserted more or less parallel with the first. X-ray films on the operating table are of no value in determining whether a screw has penetrated the hip joint.

After adequate internal fixation the wound is irrigated and closed in layers. At times, the capsule can be closed but this is not essential. A pressure dressing is applied and the patient is placed in bed on his back for additional pressure over the buttock.

No postoperative immobilization is necessary but preferably flexion of the hip is avoided as this would bring the femoral head against the replaced fragments. The patient may be turned face down or on either side in bed but significant flexion of the hip is avoided for three of four weeks until some union of the fracture has taken place. Of course, this occurs rapidly in the cancellous bone of the pelvis. Then the patient may sit in a chair and begin ambulation on crutches but the hip should be protected from weight-bearing until at least two months after injury.

Pitfalls and Precautions

1. Do not postpone reduction of the dislocation until the operation for the acetabular fracture. Reduction of the dislocation is an emergency.
2. Do not underestimate the size of a fragment of posterior acetabulum. It is always larger than it appears on roentgenogram. If in doubt, operate.
3. Make the incision in the skin and gluteus maximus of adequate length for good exposure.
4. Adequately protect the sciatic nerve.
5. Use enough screws to stabilize the posterior fragment in excellent reduction.

FRACTURES OF THE SHAFT OF THE FEMUR

Fractures of the femoral shaft (from a point 1 inch below the level of the lesser trochanter to about 5 inches above the knee joint) in adults are preferably managed by open reduction and internal fixation with an intramedullary nail supplemented, if necessary, by additional fixation with loops of wire, bands, screws or plate and screws. The objective of the surgery is internal fixation of the fracture so stable that all external immobilization may be omitted.

Intramedullary nailing provides so many advantages over all other methods it should be employed if at all possible. In comparison with others, this method gives the highest percentage of united fractures in the best apposition, length and alignment with the best preservation of motion in the joints and strength and tone of the musculature of the extremity. Not only may all external splinting be omitted but the patient may be out of bed in a chair shortly after operation and begin ambulation on crutches a few days later, often with guarded weight-bearing. The beneficial effect toward the patient's well-being and the tremendous economic advantages are obvious. Since any fracture of the femoral shaft which could be stabilized by multiple screws or a plate and screws can be stabilized better by intramedullary nailing with supplemental fixation as necessary with all its advantages, these former technics are now almost obsolete. Intramedullary nailing for fractures of the femoral shaft, with supplemental internal fixation if indicated, is so advantageous, the burden of proof is on the surgeon who selects another method for this injury.

The Kuntscher clover-leaf nail appears to be preferable to other nails for several reasons. Because of its design and structure it is perhaps stronger than all others. The nail takes a firm purchase within the femoral canal especially after reaming of the isthmus at the junction of the upper and middle thirds of the bone. A precision-

tight fit follows testing and selection of a nail of the proper diameter. A nail of the desirable length can be obtained easily during the operation as a longer nail can be sawed off as is necessary. The Hansen-Street diamond-shaped nail is probably adequate but the Kuntscher nail seems preferable. The technic for the insertion of the latter will be described.

Technic: Preoperative observations—The desired nail length may be estimated satisfactorily by measuring on the uninjured side the distance from the tip of the greater trochanter to the lateral margin of the knee joint and subtracting 3 to 4 cm. Or, a nail of known length may be taped on the lateral side of the uninjured thigh and separate roentgenograms made of the regions of the hip and knee. Comparison of the relation of the ends of the nail with the femur permits a rather accurate appraisal of the length of the nail which should be used. Of course, either of these methods is based on the assumption that the femurs were of equal length prior to injury. The width of the femoral canal may be observed and measured on the roentgenograms of both the injured and uninjured side and some idea obtained as to the diameter of the nail which should be used but this will really be determined during the operation as described below.

Operative Position: The patient is placed on an ordinary operating table on the uninjured side with hips and knees in moderate flexion. The kidney supports may be used to advantage in keeping the patient on the side. A long sheet is folded over and over until it is about 4 inches wide and then it is looped through the perineum with the ends presenting at the head of the table. This will be used to help provide countertraction during reduction of the fracture.

Preparation and draping are not easy with the patient on the side, particularly if the femoral fragments are to be held reasonably immobile. Preparation must cover a large area of the outer side of the hip and extend circumferentially about the thigh to a level shortly below the knee. To maintain elevation of the extremity for this and subsequent draping without excessive sagging at the fracture site and without contamination of the drapes is most difficult.

A rather simple expedient to facilitate preparation and draping is worthy of description. An ordinary Buck's traction is applied to just below the knee. If fixed or balanced skin traction has been used previously, the Buck's traction will already be in place. A sheet is

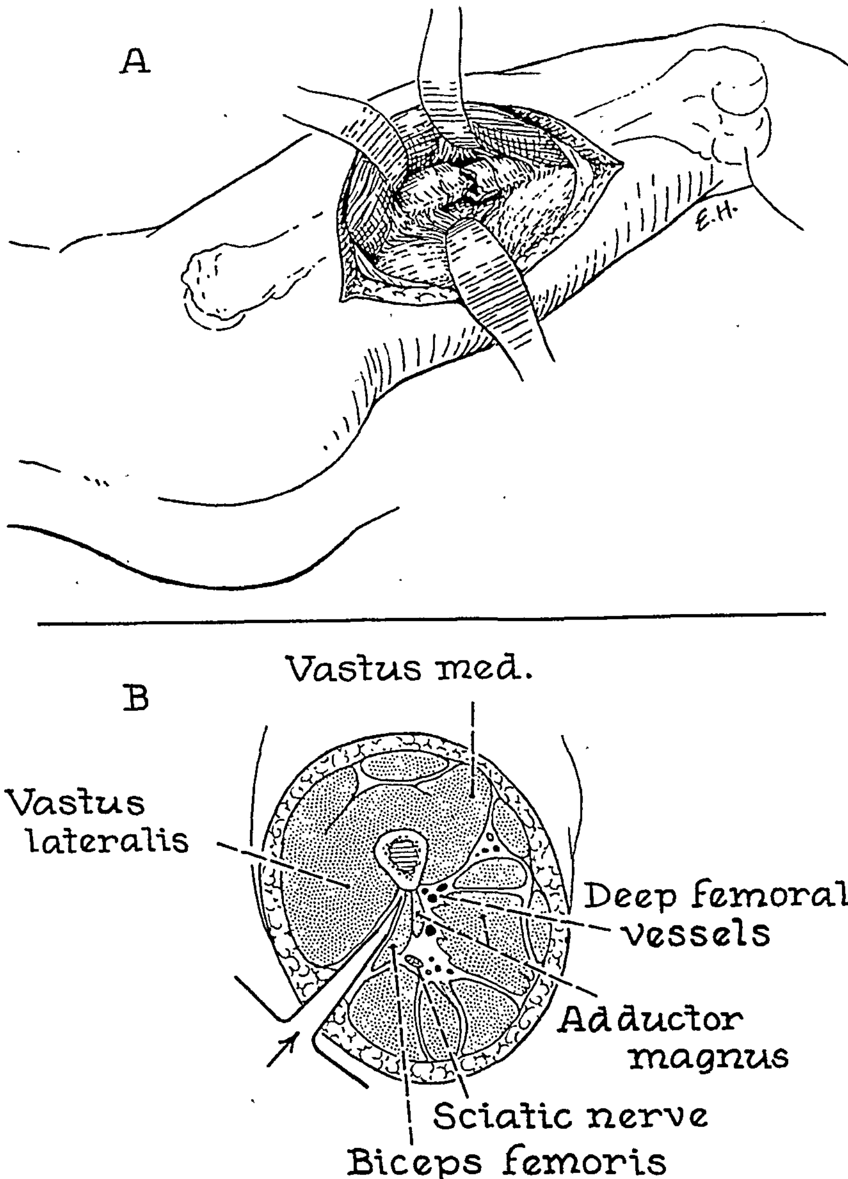


FIG. 40—*Technic of Intramedullary Nailing of Fracture of Shaft of the Femur* (*see text*). (A) Exposure of fracture through posterolateral approach. (B) Cross section of thigh showing posterolateral approach to the femur.

guide pin is withdrawn and the nail is driven to within an inch or two of full insertion.

At this point anteroposterior and lateral roentgenograms of the distal portion of the femur are valuable to verify that the nail is passing true (which indicates good alignment of the fragments) and that its length has been selected correctly. If the films show a satis-

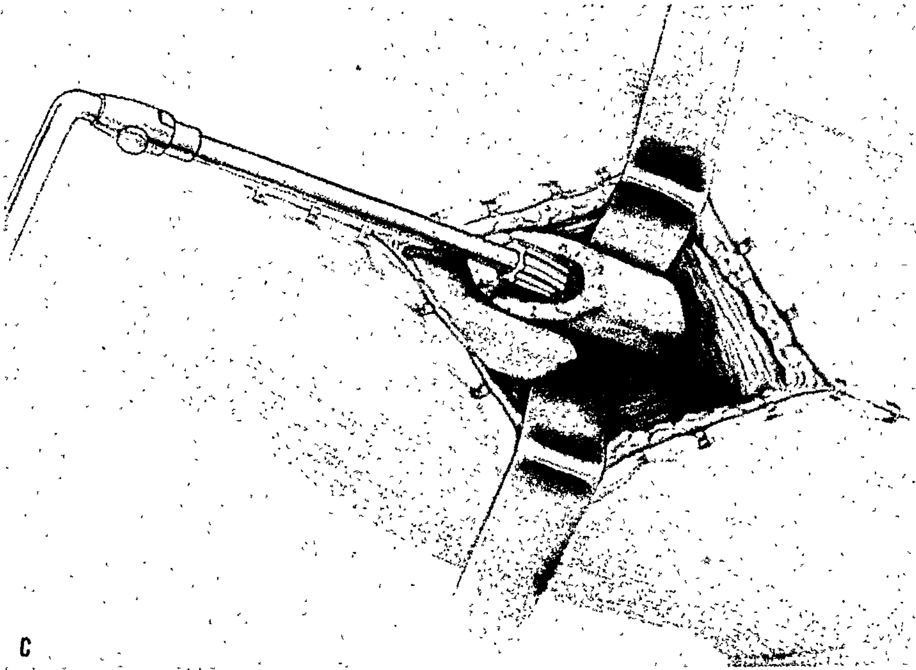


FIG. 40—(C) The isthmus (about the level of the proximal and middle thirds) of the proximal fragment is reamed to the diameter of the largest nail which will enter this fragment at the fracture line. If the fracture is within the isthmus, the caliber of the reamer and the size of the nail to be used may be determined best by first reaming the distal fragment.

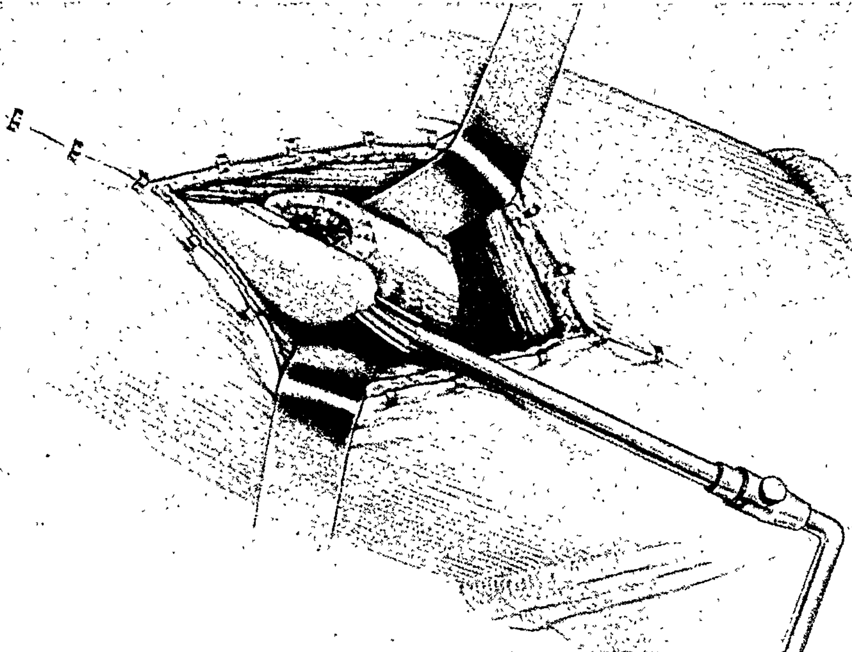
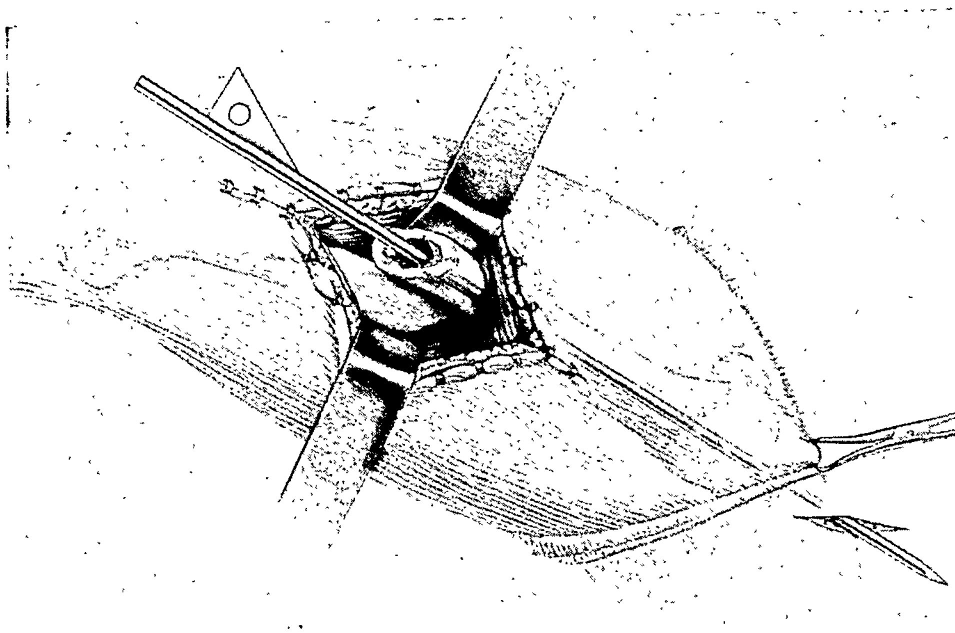
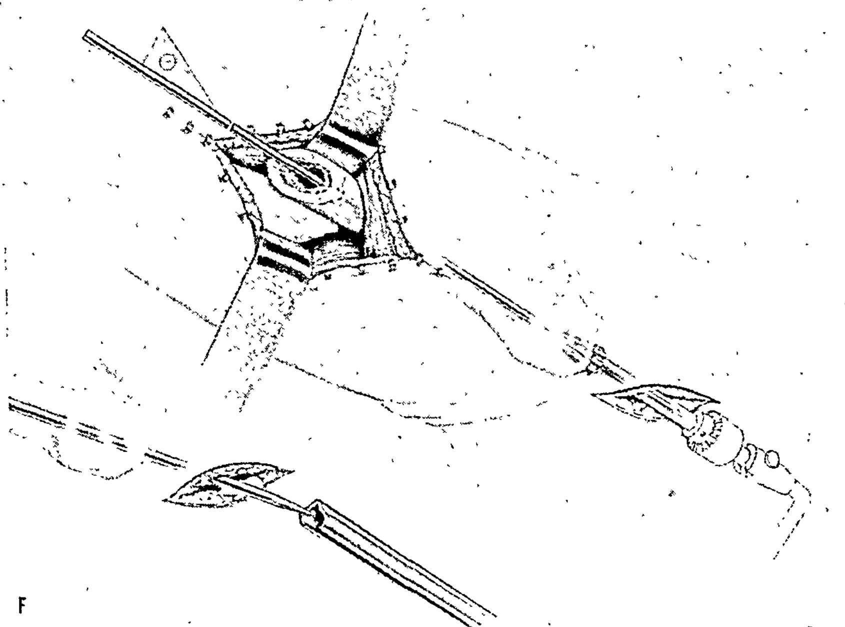


FIG. 40—(D) The distal fragment also may be reamed (see legend for C). This is not necessary in fractures distal to the isthmus.



E

FIG. 40—(E) The guide pin is introduced retrograde and made to emerge through a short incision superior to the greater trochanter.



F

FIG. 40—(F) Using a counter-bore slightly smaller in diameter than the nail to be used, a hole is made in the superior cortex just inside the greater trochanter.

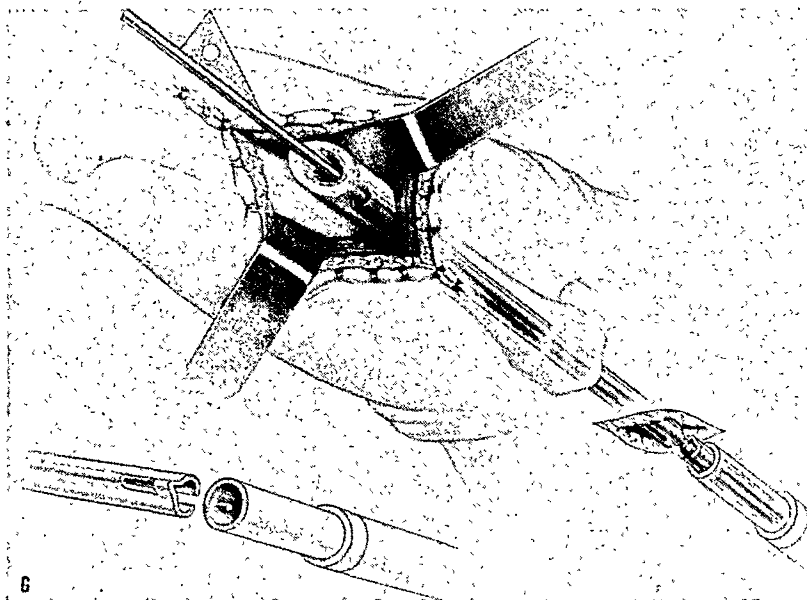


Fig. 40—(G) The selected nail is driven over the guide pin until it is well seated in the proximal fragment.

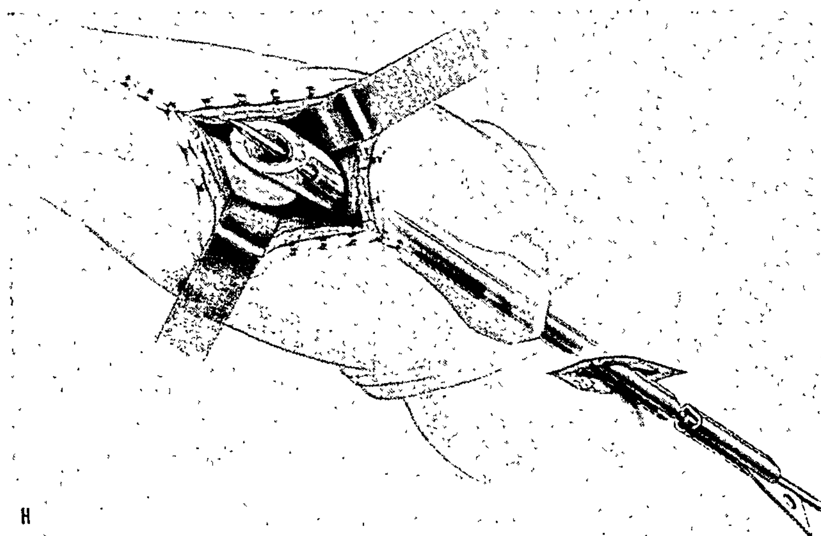


Fig. 40—(H) The guide pin is withdrawn and inserted down the canal of the femur to the fracture site.

factory direction of the nail, it is driven home so that only the eye remains protruding (fig. 41). If the direction is not correct the nail is withdrawn until it is no longer in the distal fragment, the angulation at the fracture site is corrected and the nail is reinserted.

Ideally, the nail extends to the level of the adductor tubercle and

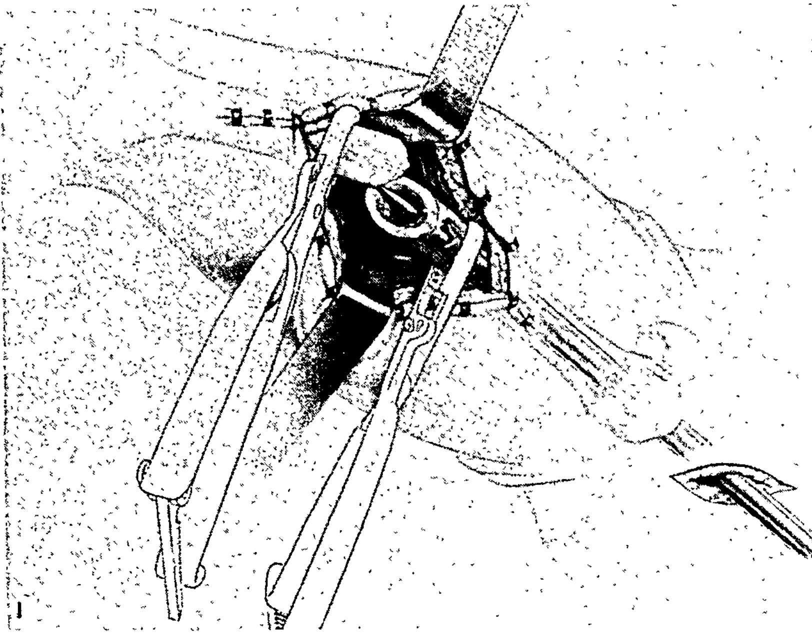


FIG. 40—(I) Then the fracture is reduced and the guide pin is inserted on down the canal of the distal fragment.

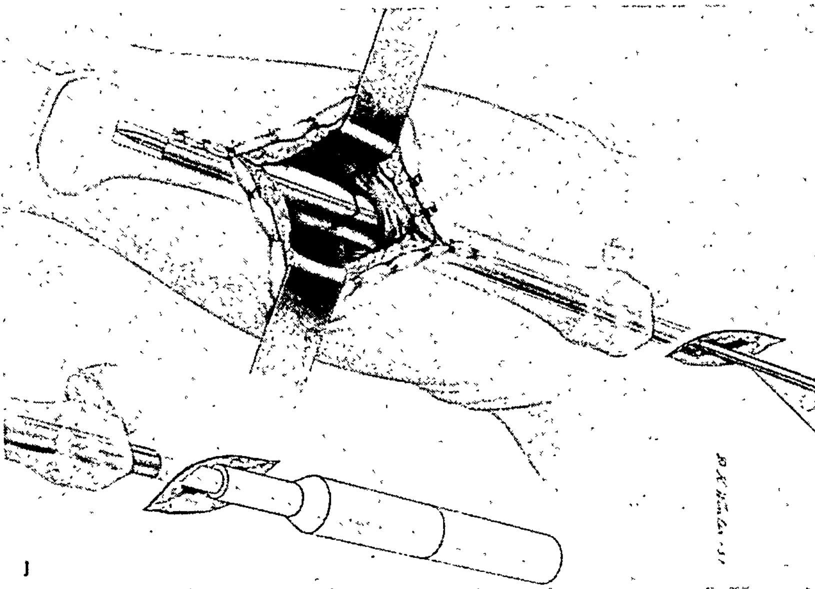


FIG. 40—(J) The nail is driven down the canal of the distal fragment, after which the guide pin is withdrawn.

this is most desirable in fractures of the lower half of the shaft of the femur. In fractures of the proximal half, the nail need not advance so far.

In comminuted and oblique fractures requiring supplemental fix-



FIG. 41—*Intramedullary Nailing of Fracture of the Shaft of the Femur.* (A) and (B) Anterior-posterior and lateral views of comminuted fracture of the shaft of the right femur in the middle third immobilized in a half-ring splint as emergency splinting.

ation for adequate stabilization (FIGS. 42–46), the surgeon must determine at the time the fracture site is exposed whether these comminuted fragments should be brought into approximation with one of the major fragments and fixed to it by means of a tangential screw, Parham band or circumferential loop of wire before the intramedullary nailing or after the latter has been completed. In most instances, the comminuted fragments will be reduced and the supplemental fixation provided after the major fragments have been reduced and the intramedullary nail has been inserted.

After adequate internal fixation has been achieved, all wounds are irrigated and closed. A pressure dressing is then applied which includes the application of elastic bandages extending from the base of the toes to well above the fracture site and in some instances in-

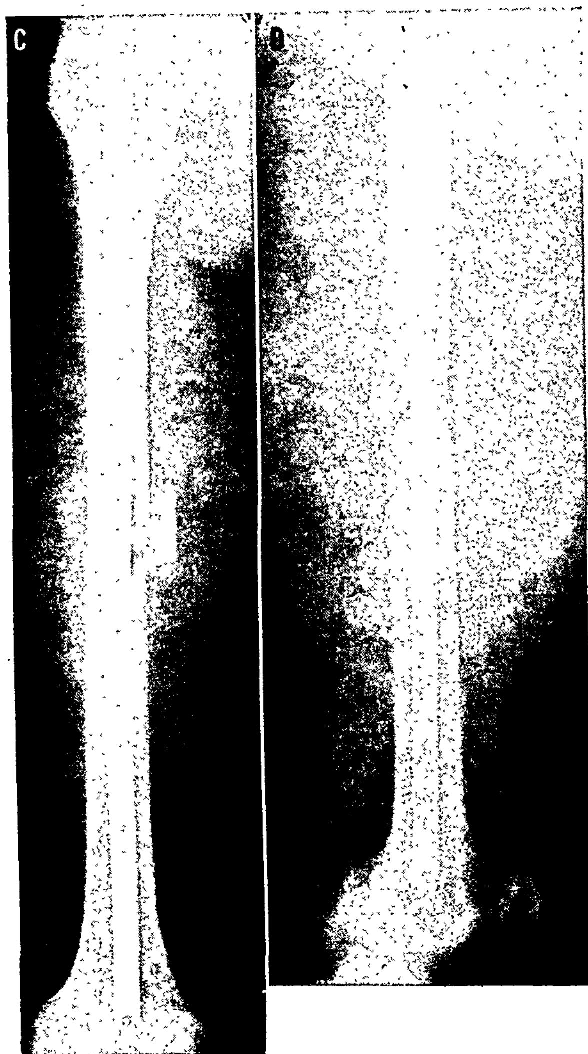


FIG. 41—(C) and (D) Anterior-posterior and lateral views showing fracture stabilized in excellent reduction by a clover-leaf (Kuntscher) intramedullary nail.

cluding a figure-of-eight bandage about the pelvis and hip in order to provide pressure at the incision for insertion of the nail.

Postoperative Management: No external splinting of any kind is necessary following an adequate internal fixation by intramedullary nailing with or without supplemental fixation. The patient may be turned from side to side promptly and sit on the bedside or in a chair at the will of the surgeon. Crutch walking is usually delayed until the wound is healed enough to permit removal of the skin sutures.

Partial weight-bearing with crutches may be permitted within a

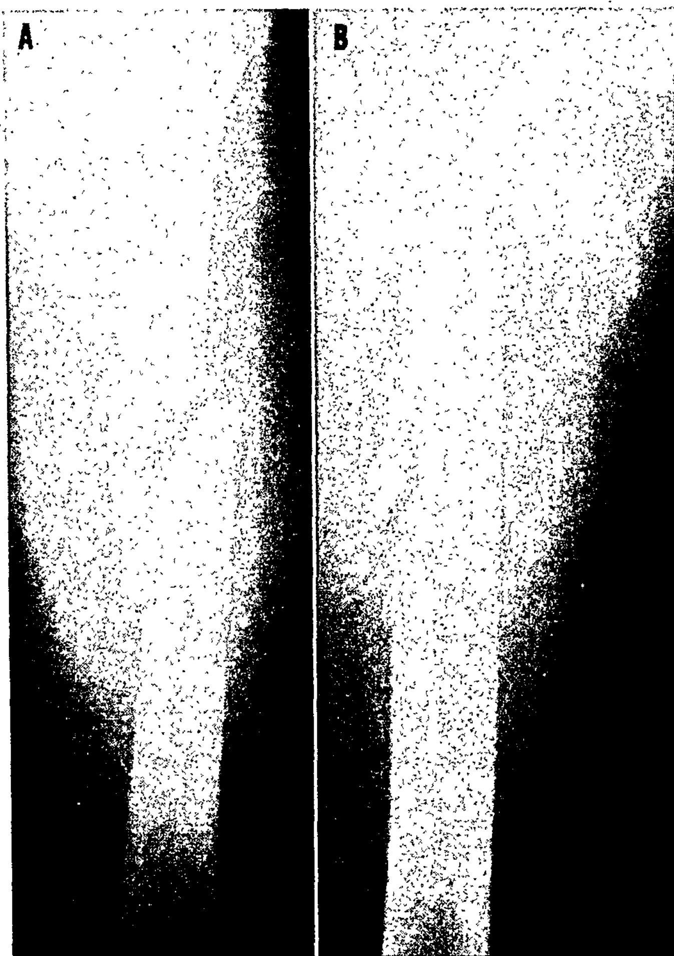


Fig. 42—*Intramedullary Nailing of Fracture of the Shaft of the Femur with Supplemental Plate.* (A) and (B) Anterior-posterior and lateral views of comminuted fracture of the shaft of the left femur at the junction of the upper and middle thirds.

few weeks in transverse or near-transverse fractures but in comminuted or oblique fractures which have required supplemental fixation, this is usually delayed for five to six weeks. Significant weight-bearing should not be permitted until there is x-ray evidence of some bony callus bridging the fracture site. On the other hand, it should be kept in mind that guarded weight-bearing with crutches may be a valuable stimulus to union of the fracture. When roentgenograms show a satisfactory bridge of callus between the major fragments, the crutches may be discarded and the patient may bear full weight on the foot and leg and resume any reasonable activities.

As a rule, the intramedullary nail should be removed after solid union of the fracture has taken place. Obviously, it is better to err



Fig. 42—(C) and (D) Anterior-posterior and lateral views of fracture site stabilized in excellent reduction by a clover-leaf intramedullary nail supplemented by a slotted plate and short screws which were used for better stabilization and particularly to prevent rotation of the fragments at the fracture site.

on the side of leaving the nail in longer than necessary than to remove it too soon. Actually, it cannot be stated that the nail must be removed. On the other hand, the patient with an intramedullary nail in place usually has a coxalgic limp until the nail is removed probably due to the irritation of the small portion of the nail which protrudes superiorly. Moreover, it is reasonable that such a large foreign body should be removed when it is no longer of value because the removal is so simple through a small incision on the lateral side of the hip a short distance above the trochanter.

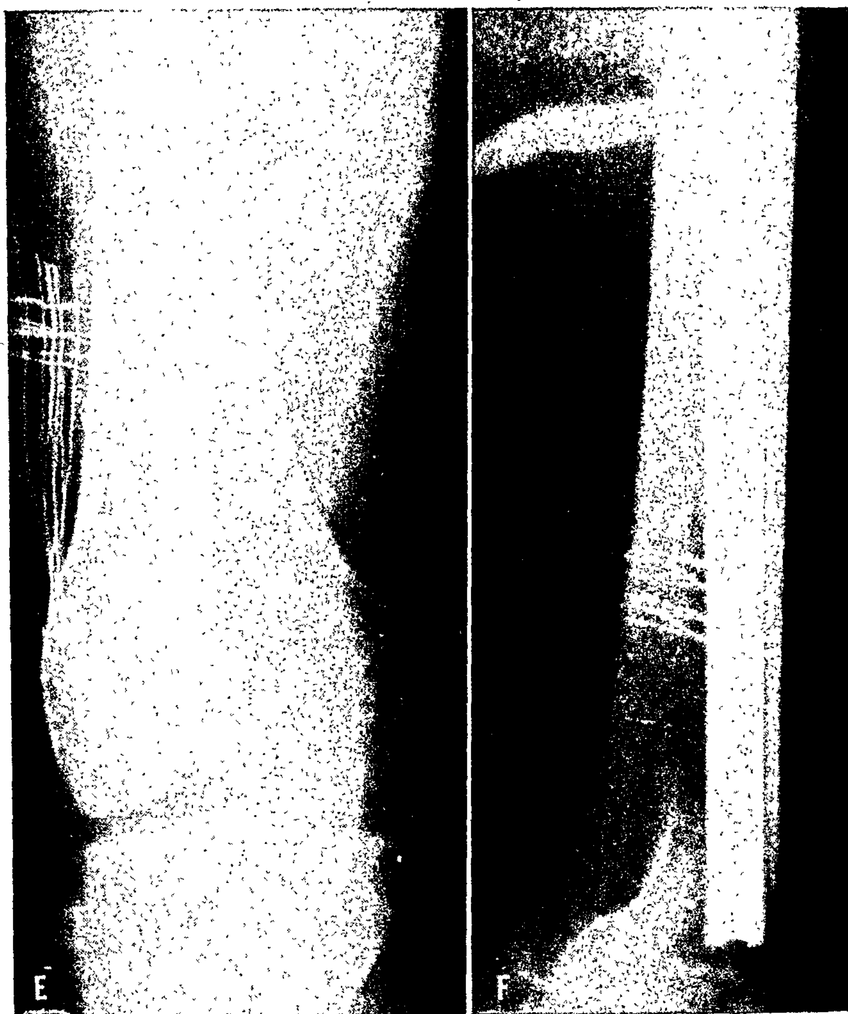


Fig. 42—(E) and (F) Anterior-posterior and lateral views of the lower portion of the femur made on the operating table to show the position and depth of penetration of the distal end of the nail.

Pitfalls and Precautions

1. Do not deny the advantages of intramedullary nailing to a patient with a fracture which can be stabilized by this method with or without supplemental fixation.

2. Do not fail to make the necessary measurements to aid in selecting a nail of proper length.

3. Be certain to have available reamers of 10 mm., 11 mm. and 12 mm. diameter and to ream the isthmus to the size of the canal just above and below it.

4. The nail must fit quite snugly but it must not be so large as to risk splitting the canal. It should pass down the canal smoothly with firm blows of the mallet.

5. If the nail becomes stuck, extract it and begin again. Always have vise-grip pliers sterile to aid in extraction in an emergency.

6. Protect alignment of the fragments continually until the nail has been driven in



FIG. 42—(G) and (H) Anterior-posterior and lateral views of fracture site after union of the fracture and removal of the intramedullary nail. Note, however, in the lateral view union appears precarious. This points up the importance of making certain that excellent and mature union of the fracture has occurred before the removal of the intramedullary nail. In this instance the nail was probably removed before it was safe but even so the extent of union was sufficient to permit resumption of function and the fracture went on to good solid union.

all the way as a safeguard against the on-going tip cutting through the cortex near the knee.

7. Avoid distraction at the fracture site; keep the fragments in contact.
8. Do not remove the nail too soon.

FRACTURES ABOUT THE KNEE

Supracondylar and Intercondylar Fractures of the Femur

While reduction of these fractures can often be achieved and maintained by either closed reduction and a plaster cast or balanced



Fig. 13.—Intramedullary Nailing of Fracture of the Distal Shaft of the Femur with Supplemental Plating. (A) and (B) Anterior-posterior and lateral views of comminuted fracture of the shaft of the left femur at the junction of the middle and lower thirds. Note the rather severe rotation of the large comminuted fragment.

skeletal traction, the best functional results are likely to follow open reduction and internal fixation. The latter method provides the most precise reduction which is mandatory when a line of fracture enters the knee joint if the smooth articular surface is to be restored. The end-results in these injuries must be measured in part by the eventual range of motion in the knee. With operative management and good stabilization of the fracture, external immobilization may be minimized or omitted which predisposes to a maximum return of motion at this point. Certainly this form of treatment minimizes the time the patient must remain in bed, reduces the period of temporary disability and favors the best functional result with such complicated injuries.

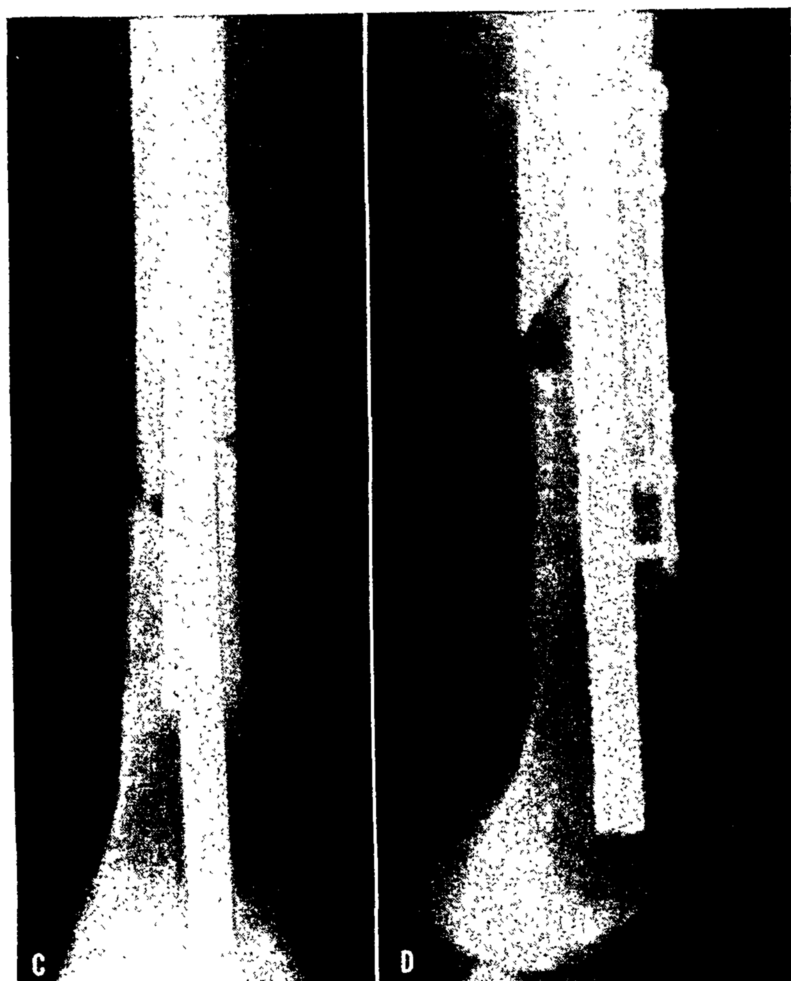


FIG. 43—(C) and (D) Anterior-posterior and lateral views of the fracture site stabilized by means of a clover-leaf intramedullary nail supplemented by a slotted plate and screws. In this instance it was necessary to place the plate on the anterior surface in order to stabilize adequately the large comminuted fragment.

While several technics have been used in this group of injuries including crossed Rush pins introduced retrograde, one through each femoral condyle (FIG. 47), Moe plate and screws, etc., in our experience internal fixation with a blade-plate such as a molded Moore hip blade-plate (originally designed for intertrochanteric fractures) or the Elliot blade-plate designed specifically for these injuries seems preferable and this technic will be described.

Technic (FIG. 48): The patient is placed on an ordinary operating table with the knee at the level of the break so that as the distal segment of the table is depressed, the knee will be flexed. The lateral sur-



FIG. 43—(E) and (F) Anterior-posterior and lateral views of the uniting fracture four months after operation. The fracture went on to solid bony union and then the intramedullary nail was removed 18 months after it had been inserted. Because early active motion of the knee could be instituted, the position of the plate on the anterior surface did not lead to restriction of motion in the knee.

face of the lower third of the femur including the fracture site is exposed through a vertical incision. The dissection passes either behind the vastus lateralis muscle or between it and the rectus femoris. The former offers a distinct advantage in that further trauma and resulting scar formation about the quadriceps tendon and extensor mechanism is minimized and at times, the knee joint bursa can be kept intact. As a rule, particularly in low fractures, the knee joint is opened for adequate exposure. The fragments are freed and then, by direct manipulation aided by manual traction on the extremity,

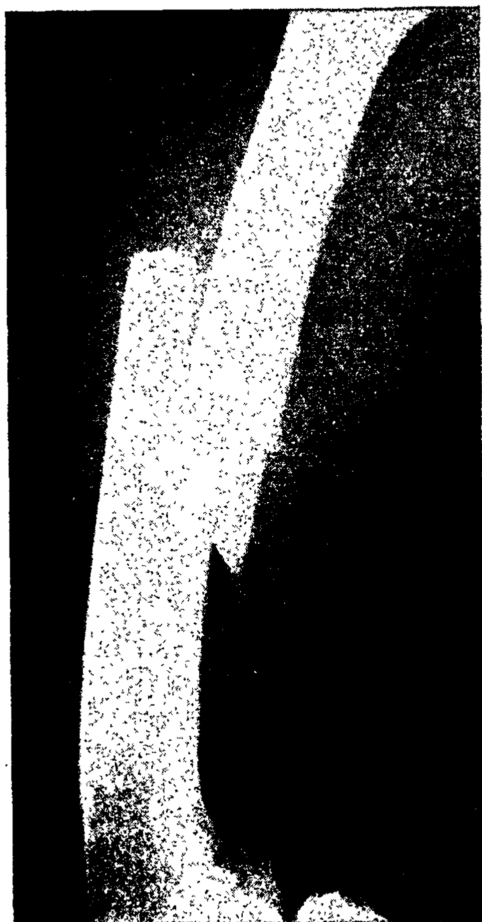


FIG. 44—*Intramedullary Nailing of Fracture of the Shaft of the Femur Complicated by an Undisplaced Fracture of the Neck of the Femur.* (A) Lateral view of comminuted fracture of the middle third of the shaft of the right femur. This was the only roentgenogram made on admission of the patient to the hospital. Note that the entire bone was not visualized.

they are reduced and held, if possible, by bone clamps. At times, when strong traction appears helpful, a Kirschner wire through the tibial tubercle and a sterile traction clevis may be used.

Some idea of the desirable contour of the blade-plate may be obtained by a study of preoperative roentgenograms including films of the lower third of the uninjured femur. Aided by a study of these and direct vision, the blade-plate is molded to fit. The blade is passed obliquely from lateral to medial into the distal fragment so that the plate comes to lie alongside the shaft. At this point, portable roentgenograms may be helpful to verify reduction. Some care is necessary to avoid accepting a valgus reduction. When the blade-plate



FIG. 44—(B) Anterior-posterior view showing stabilization of fracture of the shaft of the femur in good position by means of a clover-leaf intramedullary nail and two supplemental loops of stainless steel wire placed circumferentially. Even though the comminuted fragment on the medial surface was not embraced by the proximal loop of wire, it remained in adequate relationship. Of particular importance note the poorly visualized fracture of the basilar portion of the neck of the femur. (C) Anterior-posterior view several days later after fracture of neck of the femur at the base had been stabilized by Knowles pins. (D) Lateral view of the fracture site made at the same time as C showing excellent apposition of the fragments in this view.

has been inserted properly the plate is then fixed to the shaft by screws (FIG. 49).

In T-fractures with separation and displacement of the condyles (FIG. 48A), the incision may be extended distally so as to cross the patellar tendon which may be severed transversely. This permits excellent visualization of the articular surfaces of the condyles. These can then be reduced accurately and held in reduction by a transfixing Webb bolt. The supracondylar fracture is then reduced

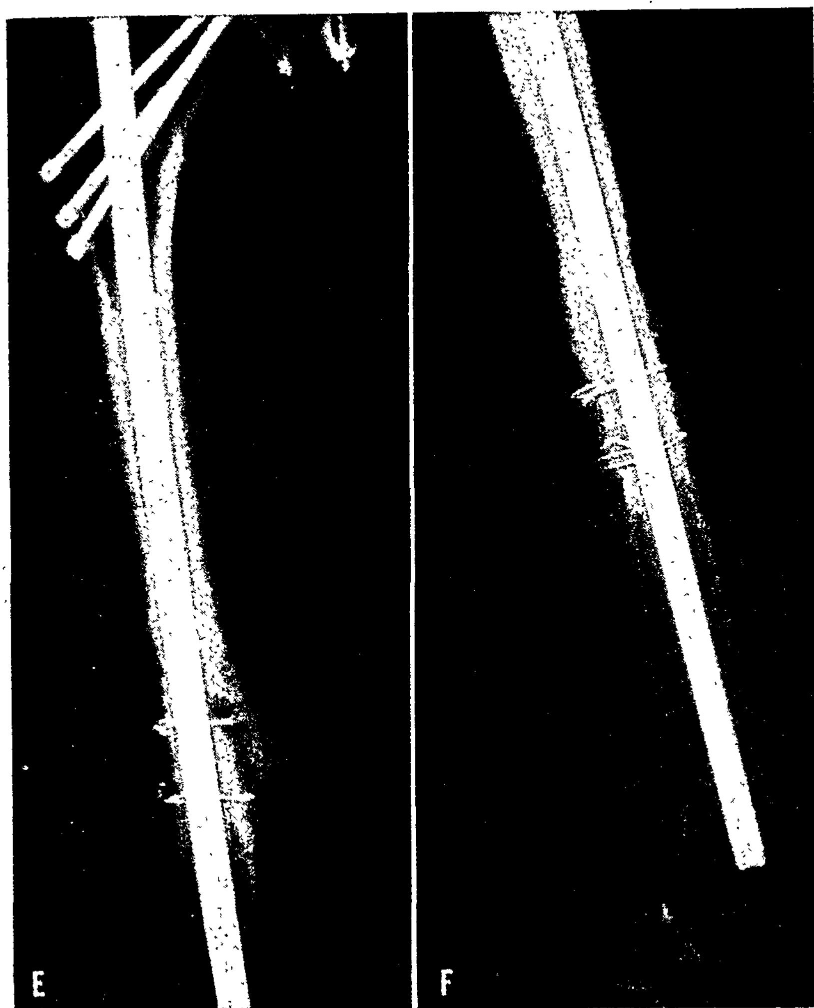


FIG. 44—(E) and (F) Anterior-posterior and lateral views of uniting fractures of the femur. The fracture in the neck of the femur is not well visualized but it went on to solid bony union as did the fracture of the femoral shaft.

and stabilized with a blade-plate by the technic described above. If the blade-plate alone appears to provide adequate stabilization of the intercondylar fracture as well as the supracondylar fracture, the Webb bolt may be removed before wound closure. Otherwise, it is left *in situ* to be removed at a later date after some bony union.

Primary Bone-Grafting: In severely comminuted fractures above the cancellous bone of the distal end of the femur, primary bone-grafting with chips of varying size from the wing of the ilium may be advantageous (FIG. 49C AND D). The chips are packed in and about the comminuted fragments in the usual manner. Primary bone-grafting may serve as a safeguard against nonunion and more-



Fig. 45—*Intramedullary Nailing of a Comminuted Fracture of the Lower Third of the Femur with Supplemental Fixation by Parham-Martin Bands.* (A) and (B) Anterior-posterior and lateral views of comminuted fracture of lower third of the shaft of the femur in an 81 year old female.

over, shorten the time of union and thereby predispose to the optimal end-result.

Following thorough irrigation and closure of the operative wound including accurate repair of the patellar tendon if it has been severed, the extremity is immobilized with the knee in moderate extension. A plaster cylinder cast extending from the groin to the lower third of the leg has proved adequate in most instances. This really serves to avoid excessive flexion at the knee which might place undue strain at the fracture site. Actually when the patellar tendon has not been severed, the plaster cast often can be removed after two or three weeks for guarded exercise of the knee, depending on the degree of comminution of the fracture. In a few instances, immobilization is not necessary. If the patellar tendon has been severed

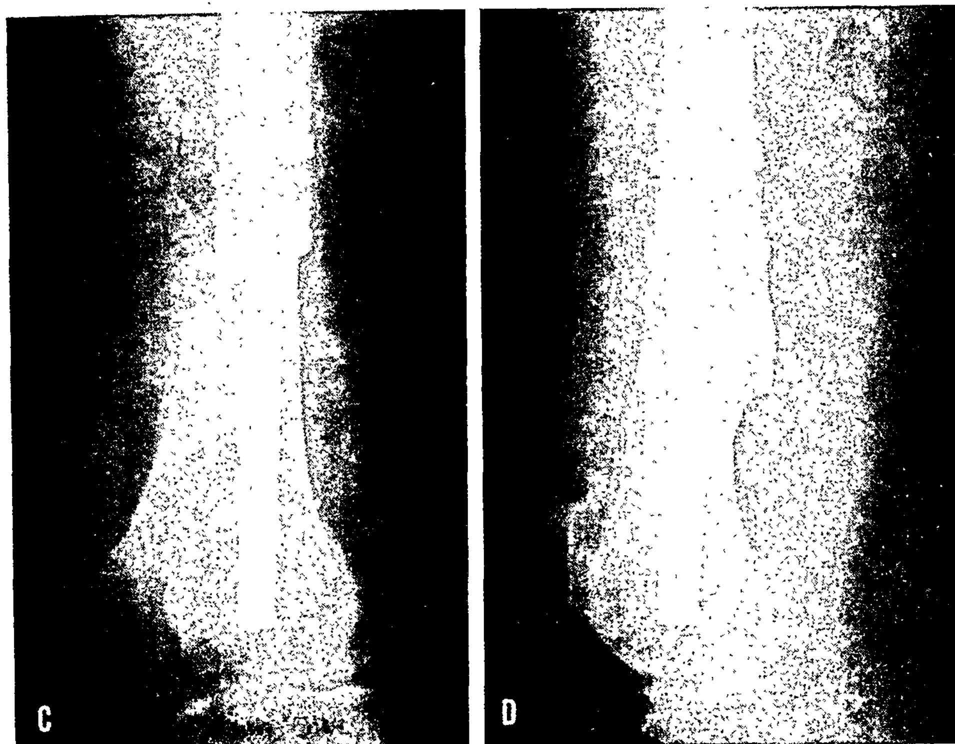


FIG. 45—(C) and (D) United fracture after internal fixation with an intramedullary nail supplemented by two Parham-Martin bands. After these films were made the bands which are beginning to cut into the cortex were removed but the nail was left for an additional four months. It was then removed under local anesthesia.

or the fracture is severely comminuted, at least six weeks of immobilization in the cylinder cast is indicated. Of course, no weight-bearing is permitted until there is x-ray evidence of solid union of the fracture.

Pitfalls and Precautions

1. Guard against valgus deformity during placement of the nail-plate.
2. Guard against fixation with fragments distracted. Do not hesitate to telescope the fragments a bit in order to obtain excellent bony contact.
3. In T-fractures, make certain that the two condyles are approximated perfectly and held so during insertion of the nail portion of the nail-plate.
4. Be sure the tip of the nail does not extrude through the medial cortex more than a few millimeters.

Fractures of the Patella

Open operation with some form of internal repair is indicated in practically every fracture of the patella with separation of the fragments. Separation of the fragments signifies some degree of disrup-



FIG. 46—*Intramedullary Nailing of Pathologic Fracture of the Shaft of the Femur.* (A) Pathologic fracture of the shaft of the right femur at the junction of the middle and upper thirds. (B) and (C) Fracture stabilized by nested clover-leaf nails. A 12 mm. nail was supplemented by a 10 mm. nail in order to adequately stabilize the fracture site.

tion of the quadriceps expansion, the repair of which is just as important as the approximation of the fragments of bone. Moreover, the latter must be achieved so accurately that the smooth articular surface of the patella is restored. If this is not feasible, those fragments which would leave an irregular articular surface must be excised. These crucial objectives of the management of separated fractures of the patella can be achieved only at open operation.

Technic: Separated fractures of the patella fall into three large groups. These are (1) transverse fractures with two large fragments, (2) comminuted fractures of the lower (or upper) portion with a large intact (upper or lower) fragment—usually at least 60 per cent

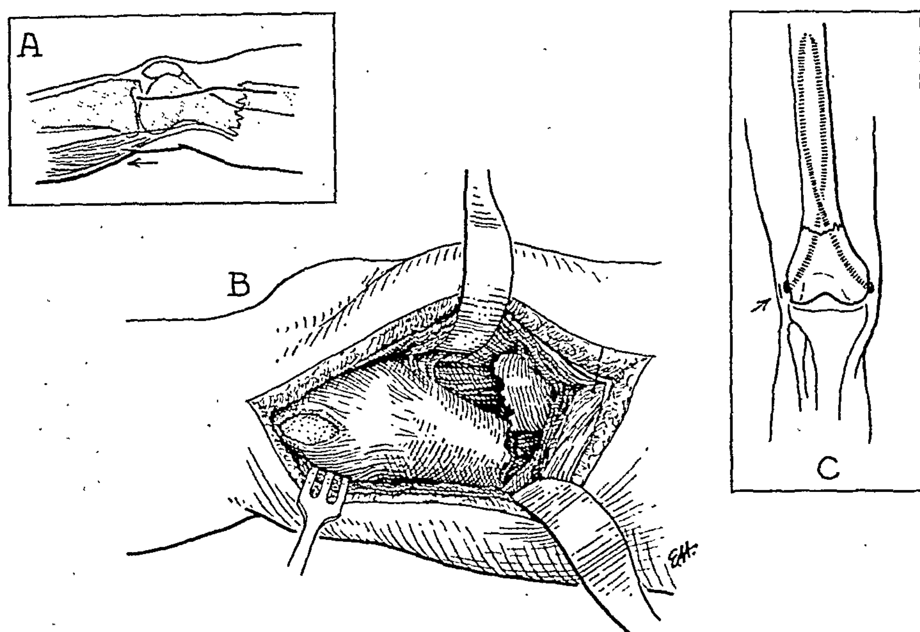


FIG. 47—*Fracture in the Distal Third of the Shaft of the Femur Stabilized with Two Rush Pins.* (A) The line of skin incision for exposure of the fragments and the lateral portion of the lateral condyle. A short incision is also necessary on the medial side for insertion of the second pin. (B) The fracture has been exposed and the point of entry of the pin through the lateral condyle has been exposed. (C) Two molded Rush pins have been inserted so as to stabilize the fracture in excellent reduction. Note that points of pins are not impinged against the cortex.

of the patella and (3) comminuted fractures of the entire bone (FIG. 50).

For all separated fractures of the patella a transverse incision across the front of the knee offers the best exposure of the fragments and torn soft tissues. A longitudinal parapatellar and a U-shaped incision are acceptable but less advantageous incisions. The skin and subcutaneous tissues are reflected so as to expose all of the fragments of the patella and the tear in the capsule and quadriceps expansion on each side. Old hematoma is removed about the fragments and from the joint. Then the problem is appraised and the decision is made as to the type of operative repair to be employed, based on the contour of the fracture lines under direct vision.

In transverse fractures the two large fragments are accurately approximated by a circumferential loop of heavy stainless steel wire woven in and out around each fragment with a large surgical needle or by a mattress suture of heavy wire placed through vertical drill

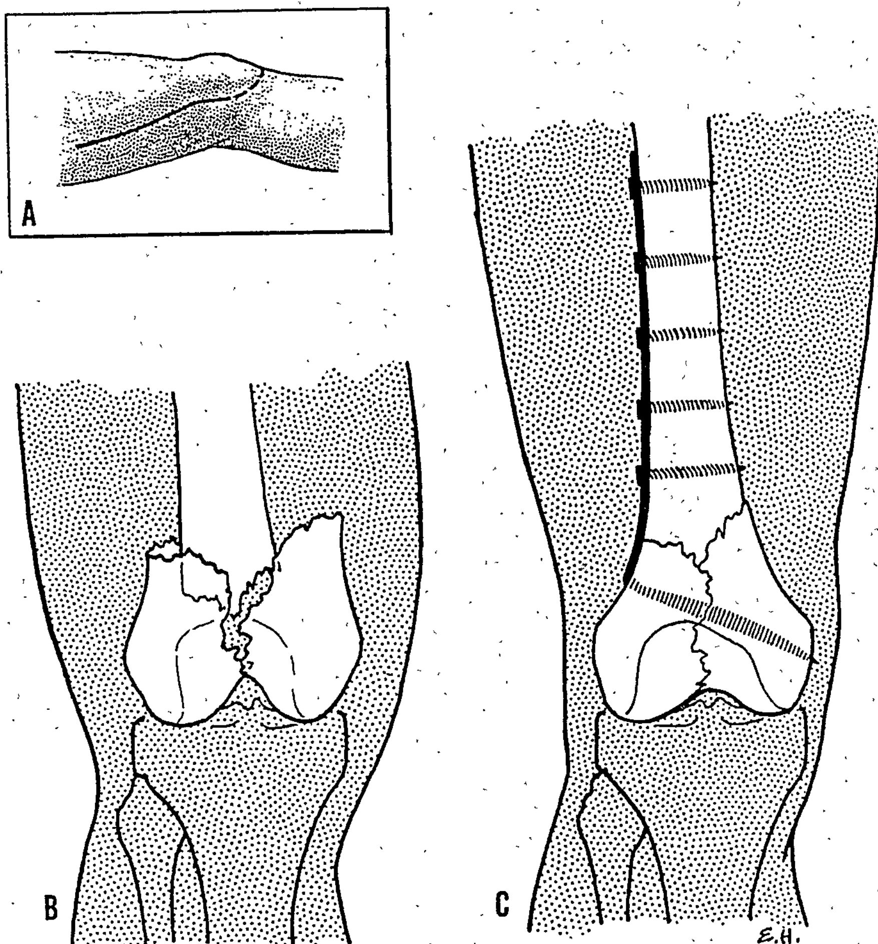


FIG. 48—*Supracondylar T-Fracture of the Femur.* (A) Lateral skin incision for exposure of the fracture. The dotted portion represents the extension of the skin incision in selected instances when the patellar tendon is to be severed for better intra-articular visualization. (B) A schematic drawing showing the problem to be overcome with internal fixation. (C) A schematic drawing showing precise reduction of the fracture lines with internal fixation using a molded blade-plate and screws. Note that the blade portion is inserted at an angle and the tip passes just through the cortex of the medial condyle.

holes in each fragment (FIG. 51A AND B). Every precaution is taken to make certain that as the wire is tightened the fragments go into accurate approximation so that the articular surface is quite smooth.

In fractures with a large intact fragment but with a comminuted fracture of either the lower or upper pole, these smaller fragments are completely excised and the patella or quadriceps tendon is approximated to the remaining raw surface of the large fragment with heavy wire woven circumferentially about the remaining fragment

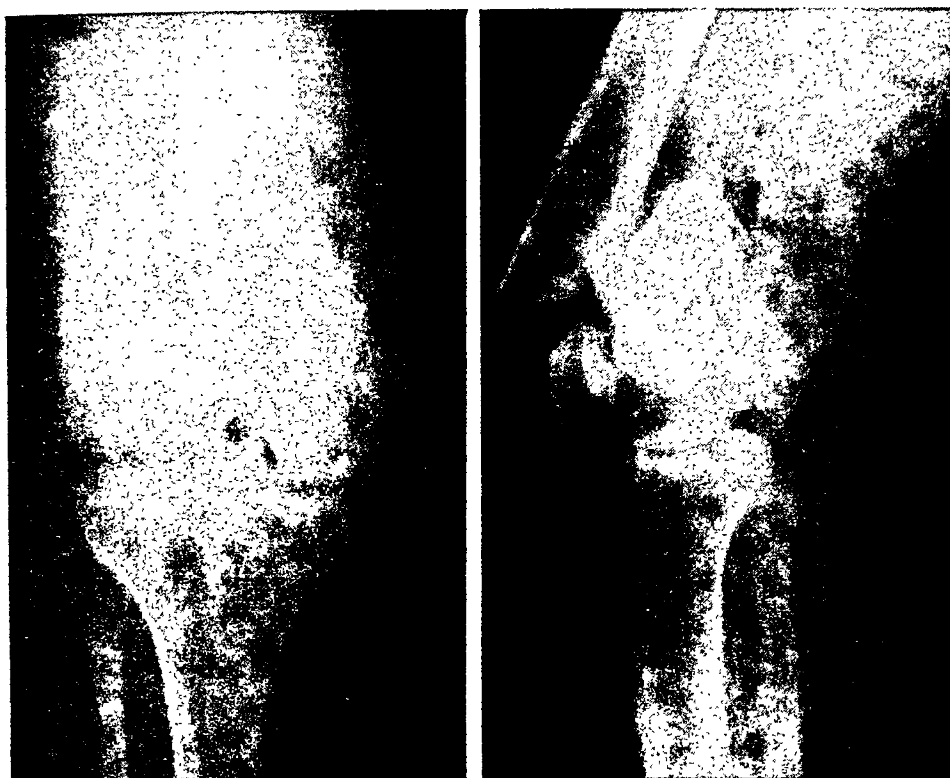


FIG. 49—*Supracondylar Fractures of the Femur.* (A) Anterior-posterior and lateral views of comminuted supracondylar T-fracture of the femur with some spread of the femoral condyles.

and then through the appropriate tendon or by a mattress suture through vertical drill holes in the fragment, then woven through the appropriate tendon (FIG. 51). Every precaution is taken to make certain that the edge of the articular surface of the fragment is buried into the mass of tendon as they are approximated.

In comminuted fractures of the entire bone, total patellectomy is usually preferable. The fragments are entirely excised and then the quadriceps and patella tendons are approximated with heavy silk. One or two mattress sutures of heavy silk are advisable.

Following each of these repairs of the fracture itself, the torn quadriceps expansion and capsule on each side are accurately and securely approximated (at times slightly imbricated) by interrupted silk sutures. Repair of these torn structures is an integral part of the operative treatment of separated fractures of the patella. The subcutaneous tissue and skin are then approximated with interrupted sutures of silk.

When repair of the separated fragments and soft tissues has been

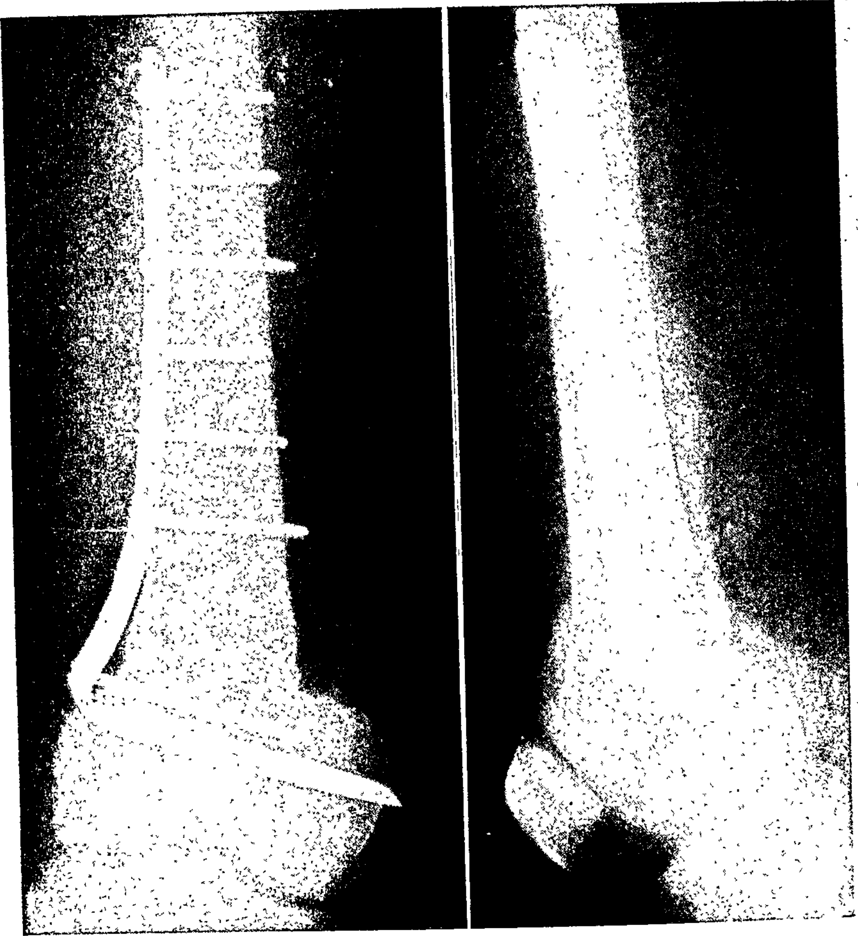


FIG. 49—(B) Fragments stabilized in excellent position by internal fixation with a blade-plate (bent Moore nail). In this instance the incision was extended distally across the patellar ligament which was severed for better exposure. The condylar fragments were fixed in perfect relationship with each other by a Webb bolt. After fixation with the blade-plate, the bolt was removed before closure of the wound. This patient obtained an excellent functional result and flexion of the knee is limited by only about ten degrees.

achieved satisfactorily, postoperative immobilization is not necessary and really is undersirable. The atony of the quadriceps muscle which accompanies all injuries and operative procedures on the knee serves to permit early active and passive flexion of the leg at the knee, which in turn obviates the tendency toward stiffness without disruption of the repair. By the time the operative incision is healed, 90 degrees of flexion is often obtainable. Also quadriceps setting exercises may be initiated immediately to minimize atrophy of this muscle. The reflex protection of the knee by the patient will avoid overzealous contractions of this muscle and, therefore, disruption of the



FIG. 49—(C) Anterior-posterior and lateral views of severely comminuted supracondylar fracture of the femur.

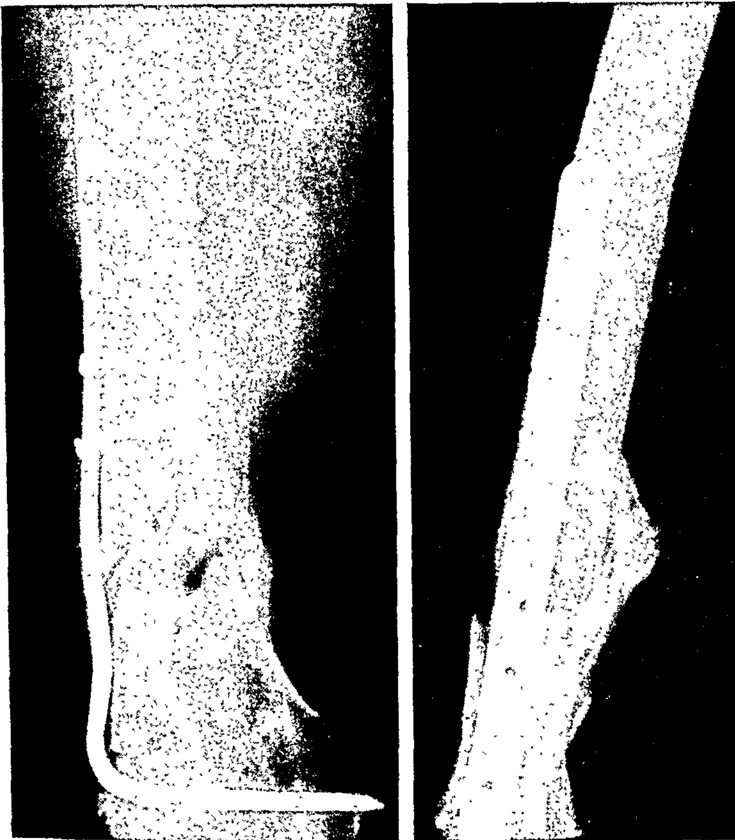


FIG. 49—(D) Anterior-posterior and lateral views showing united fracture several months later after internal fixation with a long blade-plate with primary supplemental bone grafting with chips of cancellous bone from the wing of the ilium.